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RESULTS OF 1/4 SCALE MODEL RADIOACTIVE FILTER TRANSPORTATION PACKAGE 9 m DROP TESTS

Report No. 90-147-K

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ABSTRACT

This report describes a series of 9 meter drop tests performed on 1/4 scale models of the Radioactive Filter Transport Package (RFTP). The drop tests were performed as part of the licensing requirements stipulated by the Atomic Energy Control Board (AECB) for the licensing of all type B(U) packages.

This report contains descriptions of the RFTP models, test procedures, instrumentation and all results measured and observed. The tests were performed at Ontario Hydro's Research Division on April 5, 1990.

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EXECUTIVE SUMMARY

RESULTS OF 1/4 SCALE MODEL RADIOACTIVE FILTER TRANSPORTATION PACKAGE 9 m DROP TEST

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Applied Mechanics Section
Mechanical Research Department

This report documents a series of 9 meter drop tests performed on two 1/4 scale models of the proposed Radioactive Filter Transport Package (RFTP). This package was designed to transport radioactive ion exchange filters and replace the aging Super Tiger Package. This report contains descriptions of the two models, test procedures, instrumentation and all test results measured and observed.

The RFTP has undergone several design changes since its conception. It was to test the latest revisions that this series of drop tests was performed. The drop tests also meet the requirements of the AECB as part of their licensing requirements for type B(U) packages. These tests involved dropping the models in two different orientations (flat side and top corner) from a height of 9 meters. These two orientations were selected because it was believed that they would cause the maximum damage to the package. The models were instrumented with accelerometers to monitor impact decelerations. Prior to and after each drop test, a helium leak test was performed on the models' inner containers to determine the effect of the drop test on the closure seal. High speed photography was also used to document the tests.

It was found that on the top corner and flat side drop, none of the overpack cover bolts broke. The maximum deceleration values measured for the top corner drop and the flat side drop averaged 672 g and 1544 g respectively. The helium leak tests performed after the drop tests indicated that there was no by-pass leakage on either model with a 5 torr pressure differential across the seal. It was also found that with a 380 Torr pressure differential there was no by-pass leakage from model A (top corner drop). Model B (flat side drop) could not be leak tested at the higher pressure differential but it was shown that there was no by-pass leakage after the drop. On both models the top and bottom dunnage holding the filter in place was damaged. The damage, however, was insignificant as these components were designed to absorb the impact energy by deforming.

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To Mr. P.D. Stevens-Guille
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RESULTS OF 1/4 SCALE MODEL RADIOACTIVE FILTER TRANSPORTATION PACKAGE 9 m DROP TEST

1.0 INTRODUCTION

Two 1/4 scale models of the proposed Radioactive Filter Transport Package (RFTP) container were manufactured and structurally tested by 9 m drops in flat side and top corner orientations.

The 9 m drop test meets one of the requirements of the Atomic Energy Control Board (AECB) for the licensing of type B(U) radioactive waste transportation containers. It is designed to demonstrate the structural integrity of the package design under severe impact loading.

This report presents the results and observations of these licensing drop tests which were performed on April 5, 1990.

2.0 MODEL DESCRIPTION

The two test models consisted of slightly modified 1/4 scale replicas of the proposed RFTP design. As displayed in Appendix B, the design included an impact resistant outer container (overpack) and a leak tight inner container.

The overpack consisted of a cup-shaped body and flat lid. Both components had a sandwich type construction with stainless steel inner and outer skins and a core of rigid polyurethane foam (approximately 312 kg/m^3). The lid was fastened to the body with 24 bolts made from a highly ductile stainless steel alloy (nitronic 60).

The inner container was basically a single layer stainless steel drum. There was a heavy stainless steel flange at the lid-body interface to provide added strength at the sealing joint. The inner container lid was fastened to the inner body with 12 bolts. The inner container fit inside the overpack container with a nominal 1/8" clearance on all sides.

A mild steel cylinder payload, modelling the in-station shielded ion exchange filter flask, sat inside the inner container and was held in place by two foam endcaps (termed dunnage). The mass of the payload model was scaled from the expected full size payload mass.

The 1/4 scale model design differed from the full scale design mainly by the addition of accelerometer mounts and foam pouring ports as indicated in the drawings. These modifications were located well away from the impact location to minimize their effect on the test. The steel wall thicknesses were the closest gauge available to the 1/4 scale thickness and were in all cases within a few thousandths of an inch of nominal 1/4 scale thickness.

The models were designated as 'Model A' and 'Model B' and each stood 0.69 m (27 in) high and 0.61 m (24 in) in diameter. Model A weighed 616.5 kg and model B weighed 624 kg. A detailed breakdown of the individual component masses is displayed as Table 1.

3.0 TEST DESCRIPTION

3.1 Drop Test

Each of the two RFTP models were dropped once from a height of 9 m in a different orientation, as shown in Figure 1.

Model B was subjected to a flat side drop. Model A was subjected to a top corner drop. Models were dropped such that their centre of gravity was always directly over the point of impact.

Before and after each drop test the following was performed: both models were tested for leak tightness; dimensional measurements were made to determine deformations; and torques were measured while removing bolts from the overpack body and the containment lid.

During assembly, overpack body and containment lid bolts were torqued to 4.24 N·m (37.5 in·lbs) in the sequence shown in Figure 2. During the removal of the lids, the bolts were un-torqued in reverse order.

High speed photography was used to record each drop test. Still photography was used to record damage.

3.2 Instrumentation

Both models were instrumented with accelerometers to obtain deceleration data. Locations for accelerometer mounts on both models were identical and are shown in Figure 3. Each accelerometer mount had various mounting positions. During each drop test, the accelerometers were mounted such that their most sensitive measuring axis was in line with the drop.

3.3 Leak Testing

Both RFTP models were leak tested prior to and after each drop test. The test apparatus used to perform these tests consisted of three major components: a vacuum bell jar, a leak detector and two mechanical roughing pumps. Figure 4 illustrates the test set-up with the various flow paths and leak detection points.

The bell jar was placed over the inner container of the model to be tested with a through fitting from the inner container to the outside of the bell jar. The bell jar and the inner container were therefore completely separate systems which could be evacuated or filled independently. The bell jar and the inner container were evacuated and tested for background helium. The inner container was then filled with helium and sealed off from the outside. The leak detector was set to sample the bell jar gas, including any material leaked from the inner container. In this way the inner container seal was tested with a pressure differential across the seal in the same direction as that experienced in actual operation.

A detailed description of the leak testing procedure and apparatus is in Appendix A.

4.0 EXPERIMENTAL RESULTS

4.1 Deceleration Data

Both models were dropped successfully and hit the target plate in the intended orientation. Signals from the accelerometers were recorded on an instrumentation tape recorder. Figures 5 and 6 show traces from both drop tests.

The peak decelerations measured at the two accelerometer mounts for the top corner drop test (Model A) were 640 g and 704 g. The impact angle was 43° from the top surface of the model and analysis of the high speed film of the impact indicated that the impact point was directly beneath the centre of gravity.

Measured peak decelerations for the flat side drop test (Model B) was 1504 g and 1584 g. The actual impact angle was approximately 2° from a nominal flat side drop with the lid hitting the target mas first.

4.2 Leak Test Data

The pre and post-drop steady state helium leak rate values for both models are summarized in Table 2.

Figure 7 to Figure 13 show the time response of the leak rates measured and summarized in Table 2.

4.3 Bolt Torques

The overpack and inner container lid bolts were tightened according to the sequence indicated in Figure 2. For both models, the bolts were torqued to the specified 4.24 N·m (37.5 in·lbs), untightened in reverse sequence to measure the release torques, then re-torqued for the drop. The pre-test and post-test release torques for each model are recorded in Table 3. In neither drop configuration were any bolts lost although several on the overpack underwent extreme deformations.

4.4 Model Deformations

For both models, The following measurements were made on the inner containers:

Surface Roughness: A physical measurement was made of the surface profile in the radial and circumferential directions.

Lid Mating Surface Waviness: The gross axial deviations of the lid mating surface was measured between each pair of bolt holes.

O-Ring Grove Waviness: The same measurement was made at 12 equally spaced locations in the o-ring groove.

I.D. Roundness: The deviation from nominal circularity was measured at 12 equally spaced locations at the inner diameter of the bolting flange.

The results of these measurements are summarized in Table 4.

In neither model did the measured surface finish of the inner container lid or groove meet the values specified in the manufacturing drawings (Appendix B, drawing 011). Table 4 indicates that the anomalies in the finish appeared to extend in the circumferential direction giving relatively larger radial surface roughness values. This data is confirmed by the observation of small circumferential scratches on the inner container o-ring groove sealing surface.

A profile of the gross deformations of the models after the drop tests is sketched in Figures 14 to 16, quantitatively showing the extent of the damage to the side drop and the top corner drop models. Photographs of all model damage are displayed in Appendix D.

5.0 DISCUSSION

5.1 Accelerometer Data

The time response of the accelerometers during impact were as expressed in Figures 5 and 6. These results demonstrate that there are much greater forces imparted to the side drop container than the top corner drop container as expressed by the higher peak g-loading. These results seem reasonable when considering the structure of the models at their respective impact points and the extent of post drop deformation each experienced.

The stated values for the deceleration of the container indicate that this package is much stiffer than the old RFTP design. The ratio of top corner drop to flat side drop acceleration, however, is very similar between the old and the new RFTP package design.

5.2 Leak Testing

As detailed in Appendix A, leak testing was performed before and after the drop test for both containers. The test procedure specified the performance of a leak test at 380 torr (1/2 atmosphere) pressure differential across the sealing boundary. However, due to an incompatibility between the helium pressure transducer and the read-out unit, several of the leak tests were performed at a much lower pressure (approximately 5 torr). Leak tests were performed on the pre and post-drop conditions of both models at a 5 torr pressure differential. A post-drop leak test was also performed on the top corner drop inner container (model A) at the originally specified pressure of 380 torr.

Figures 7 to 10 are graphs of the helium leak rate as a function of time from the moment of introduction of helium in the inner container. These graphs record the leak rate at a pressure differential of approximately 5 torr across the inner container sealing boundary for models A and B. The characteristic 8 to 10 minute time delay before leakage values were observed is indicative of permeation leakage and not by-pass leakage which would show a substantial leakage rate instantaneously. One can conclude, therefore, that there was no observable by-pass leakage in either the pre or post-drop tests at the 5 torr pressure differential.

Figure 11 indicates the leakage rates over time of post-drop model A (top corner drop) which was subjected to 380 torr (1/2 atmosphere) pressure differential across the sealing boundary. The 4.0×10^{-5} std cc/sec leak rate observed is approximately two orders of magnitude larger than the original leak test values, when the pressure differential was lower by a factor of almost 100. This 4.0×10^{-5} std cc/sec leak value is consistent with the leak rate range indicated in manufacturer's data for the seal material in this geometric configuration.

The model B (side drop) inner container was already unbolted and so could not be leak tested at the required 380 torr pressure differential immediately following the drop. It does, however seem reasonable to make several conclusions about the leak values that would have been observed at this pressure.

Plots of the leak response over time in the pre and post-test conditions at the 5 torr pressure differential for both models (Figures 7 to 10) show very similar behaviour. Because the leakage is very similar for pre and post-drop tests, one can conclude that the seal condition did not change appreciably as a result of the drop tests. This implies that the leak response over time at 380 torr

pressure differential for model B may be similar to the time response of model A at 380 torr. It also seems reasonable to conclude that there would have been no by-pass leakage in the model B container at the 380 torr pressure differential.

In order to provide supporting evidence for this conclusion, the model B inner container was reassembled and the lid bolts torqued to the originally specified values. Two leak tests were then performed on this container, one at approximately 5 torr and one at 380 torr. Figures 12 and 13 are plots of the time response of the leak rates observed from these tests. In comparing the shape of the post-drop leak test response (Figure 10) to the post-disassembly leak test (Figure 12), both performed at 5 torr, one can see the similarity in shape and steady state value between the two plots. This suggests that the seal was in substantially the same condition as before disassembly and that the post-disassembly 380 torr test (Figure 13) would be a good representation of a 380 torr test performed immediately before the inner container disassembly. Figure 13 also exhibits no by-pass leakage supporting the conclusion that there would also have been no by-pass leakage in the original post-drop configuration at 380 torr.

One further argument supports the conclusion that no by-pass leakage would have existed in the immediately post-drop configuration. Based on the bolt torques indicated in Figure 3, the tension on the inner container lid bolts ranged from 6.59 MPa to 19.8 MPa on post-drop model B. The addition of 380 torr pressure on the inside of the container would add 0.05 MPa to the stress on each bolt. This added load would not be sufficient to move the upper lid significantly and therefore would not disturb the seal. The conclusion could be drawn that this increase in pressure does not effect the seal surface. No by-pass leakage would be observed at 380 torr since none was observed at 5 torr.

5.3 Bolt Torques

As displayed in Table 3, the untorquing values varied from the nominal 4.24 N·m value in the undamaged pre-drop models as well as in the post-drop models. The post drop untorquing values (and therefore the bolt tensile stress) show somewhat more variation than the pre-drop. This variation demonstrates the existence and location of damage to the containers. In all cases, however, only moderate change in bolt stress was observed and in no case did a bolt become relieved of all tensile stress.

5.4 MODEL DEFORMATIONS

Figures 14 to 16 demonstrate the gross deformations of the overpack lid and body for models A and B.

For model A, photographs of the damage are shown in Figures D7 to D20. Most of the energy of the 9 m fall was absorbed in the plastic deformation of the outside of the overpack lid and very little deformation occurred on the inside, except for a slight bowing of the inner container lid. As a result, there was little increase in the waviness of the inner container sealing surface or out-of-roundness of the bolting block (as shown in Table 4). In both cases the deformation was so small as to have negligible effects on the containment seal.

For model B, photographs of the damage are shown in Figures D21 to D37. for the flat side drop, the overpack body and lid was somewhat flattened on the impact side. The residual deformations on the inside of the overpack body appear small. There are reasons to believe, however, that the inner container underwent some small deformation after the flat side drop. Evidence to this effect is the increase of the maximum relative out of roundness from 0.2 mm to 1.2 mm as a result of the drop as indicated in Table 4. Another supporting observation is that the inner container lid met some resistance before sliding into position with the body after the drop. In both cases the deformation was

so small as to be insignificant for the containment seal. As with model A, the surface waviness changed a negligible amount as a result of the drop.

6.0 CONCLUSIONS

Two 1/4 scale models of the proposed RFTP container were manufactured and structurally tested by 9 m drops in flat side and top corner orientations. The deceleration of the models was found to average 1544 g for the flat side drop and 672 g for the top corner drop. The inner container seal was shown to have only permeation leakage before and after the drops for both models at a 5 torr across seal pressure differential. This seal also showed only permeation leakage after the top corner drop with a 380 torr across seal pressure differential. It was also concluded that the post flat side drop model showed no by-pass leakage with a 380 torr pressure differential. In addition, the overpack body remained intact with the lid fastened securely after both drop orientations.

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1. "Transportation Packaging of Radioactive Materials Regulations", Registration SOR/83-740 29 Sept 1983. Atomic Energy Control Act.

2. Zane, R., "Results of 1/4 Scale Radioactive Filter Transportation Package Model 9 m Drop Tests", Ontario Hydro Research Report no. 87-182-K, January 14, 1988.

Table 1: Model Mass Breakdown

	Model A	Model B
Overpack		
Overpack Lid	73.5	73.5
Overpack Body	232.0	233.0
Total Overpack Mass	305.5	306.5
Inner Container		
Lid	16.5	15.5
Bolts	0.5	0.5
Body	34.5	33.5
Top Dunnage	13.5	13.0
Bottom Dunnage	8.5	8.5
Payload	226.0	233.0
Total Inner Container Mass	299.5	305.0
Rigging, Instrumentation, Etc.	11.5	12.5
Total Model Mass	616.5	624.0

Table 2: Steady State Helium Leak Rate Values

Pressure (torr)	Model	Steady State Helium Leak Rate Values (std cc/s) Pre-Drop	Post-Drop	Post-Disassembly
5	A	2.4×10^{-7}	2.2×10^{-7}	
	B	5.0×10^{-7}	7.0×10^{-7}	5.0×10^{-7}
380	A		4.0×10^{-5}	
	B			7.8×10^{-5}

Table 3: Release Bolt Torques

Overpack Cover Bolts

	Model A Release Torque (in.lbs.)		Model B Release Torque (in.lbs.)	
Bolt #	Pre-Drop	Post-Drop	Pre-Drop	Post-Drop
1	27	too bent	24	27
2	28	17	0	14
3	31	47	17	34
4	19	33	0	38
5	19	34	18	40
6	17	16	5	44
7	30	40	9	25
8	15	43	11	38
9	20	16	0	30
10	23	38	28	43
11	22	26	8	35
12	27	49	10	42
13	22	70	20	13
14	24	25	10	22
15	24	53	16	23
16	18	23	7	47
17	22	20	5	23
18	24	50	24	4
19	34	43	15	44
20	24	42	14	14
21	24	40	23	32
22	20	15	12	40
23	21	30	21	28
24	20	28	22	54

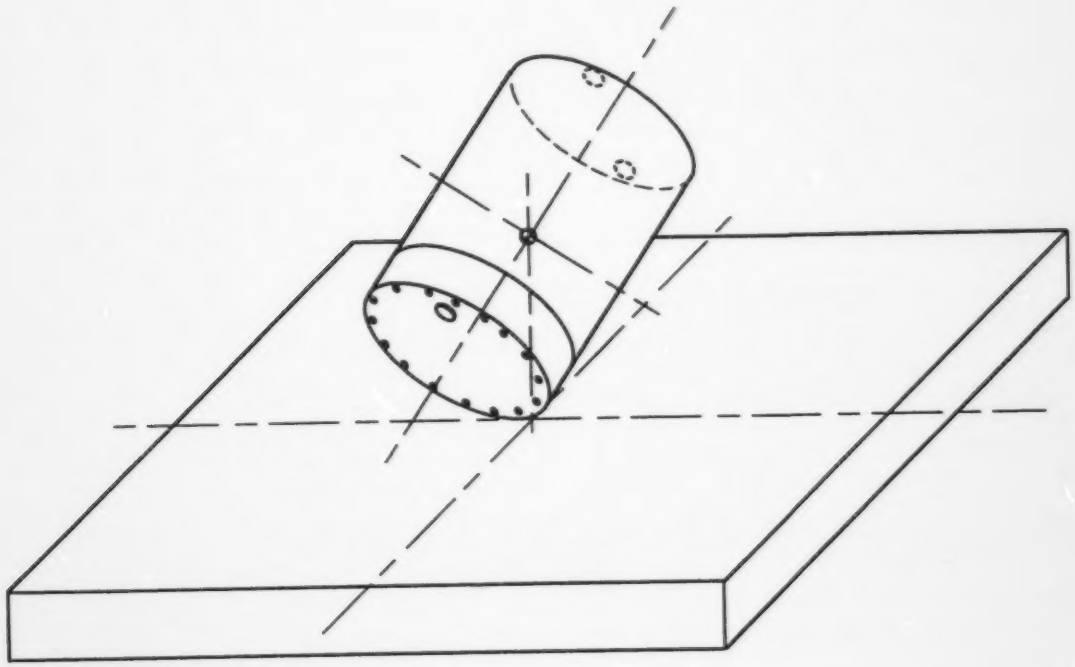
Inner Container Lid Bolts

	Model A Release Torque (in.lbs.)		Model B Release Torque (in.lbs.)	
Bolt #	Pre-Drop	Post-Drop	Pre-Drop	Post-Drop
1	19	4	17	8
2	15	28	16	18
3	20	20	29	18
4	19	22	29	10
5	19	50	21	8
6	17	24	26	20
7	22	14	53	22
8	27	40	31	24
9	26	10	29	24
10	23	20	24	18
11	21	23	32	14
12	21	30	32	20

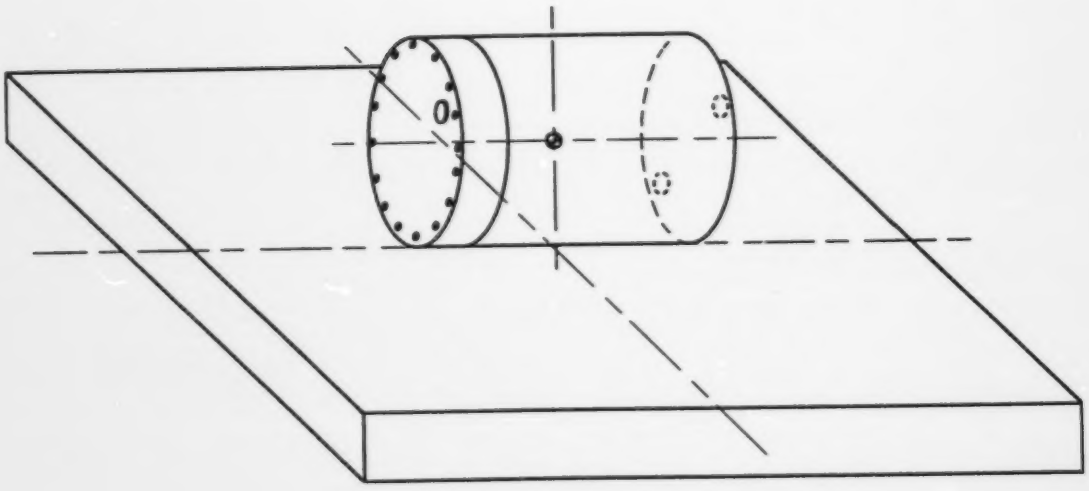
Table 4: Model Deformations and Surface Finish

		Model A	Model B
O-Ring Groove Surface Finish			
Radial Direction:	Peak to Peak	5.0 μm	5.0 μm
	Average (R_a)	1.0 μm	1.0 μm
Circumferential:	Peak to Peak	4.0 μm	4.0 μm
	Average (R_a)	0.6 μm	0.7 μm
Lid Mating Surface Waviness[1]			
Pre-Drop		0.2 mm	0.2 mm
Post-Drop		0.7 mm	0.4 mm
O-Ring Groove Waviness[1]			
Pre-Drop		0.1 mm	0.2 mm
Post-Drop		0.1 mm	0.3 mm
I.D. Maximum Relative Out of Roundness[2]			
Pre-Drop		0.1 mm	0.2 mm
Post-Drop		0.3 mm	1.2 mm

[1] Maximum peak to peak deviation.
[2] Maximum deviation of the out of roundness of 2 diameters on the same model.



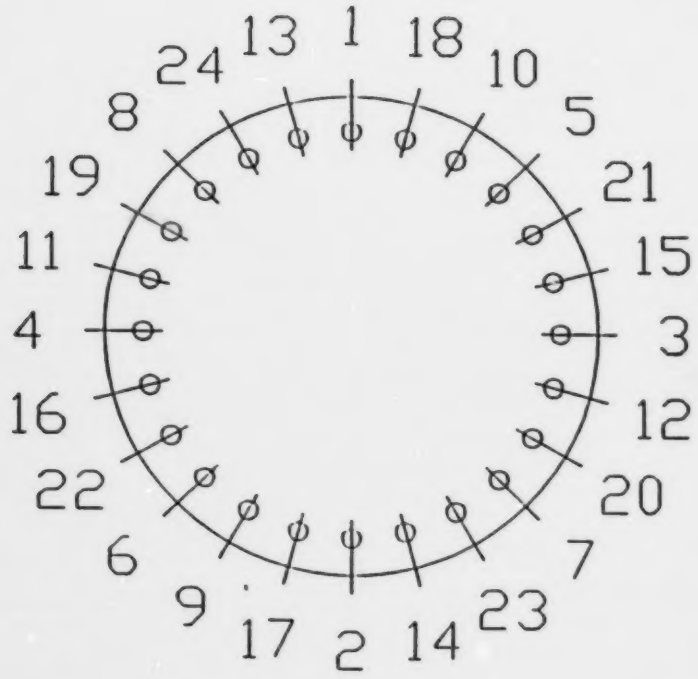
Top Corner Drop
Model A



Flat Side Drop
Model B

Figure 1: Model Drop Orientations

24 Bolt Sequence



12 Bolt Sequence

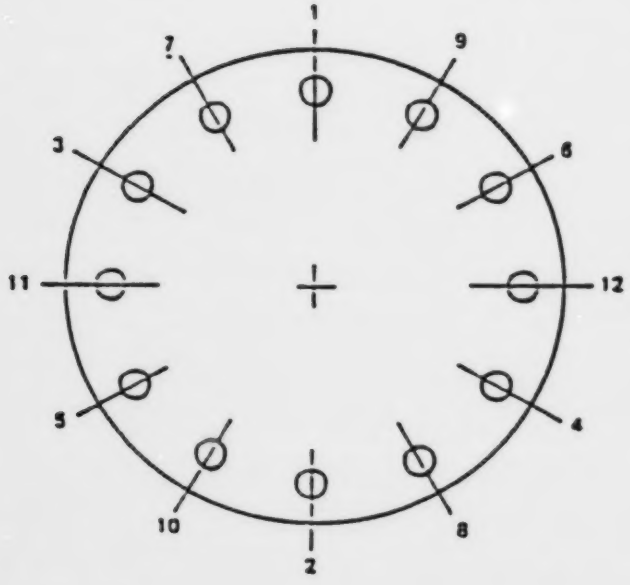


Figure 2· Bolt Torquing Patterns

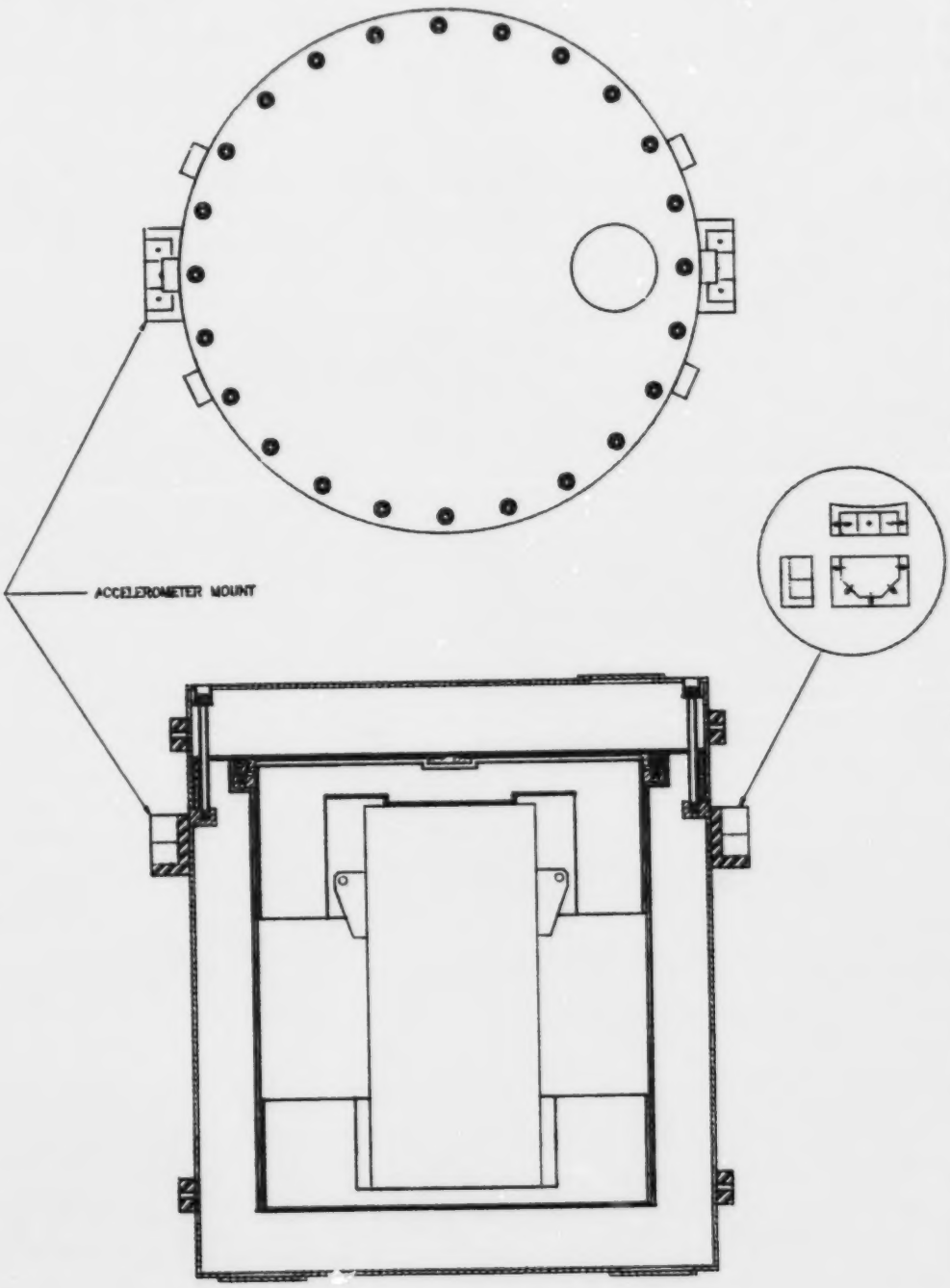


Figure 3: Accelerometer Mount Locations

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1/4 SCALE MODEL RADIOACTIVE FILTER TRANSPORTAION PACKAGE ACCELEROMETER MOUNT LOCATION

designed by	approved by
C.N. / J.H.	
date MAY 18, 1990	checked by C.N. / N.S.
scale NTS	dwg no 218 rev 00

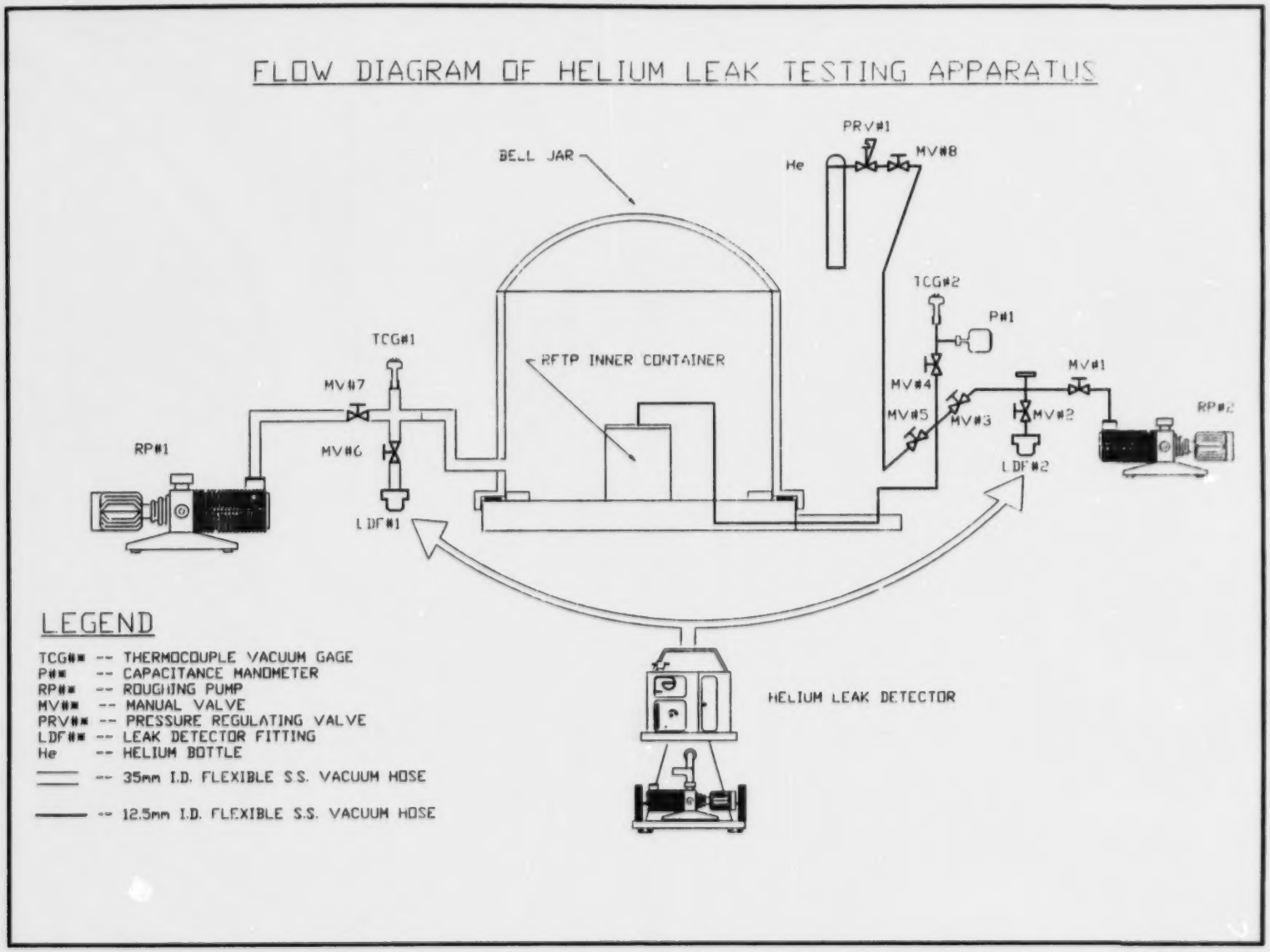


Figure 4: Flow Diagram of Helium Leak Testing Apparatus

QUARTER SCALE RFTP MODEL: A TOP CORNER DROP TEST

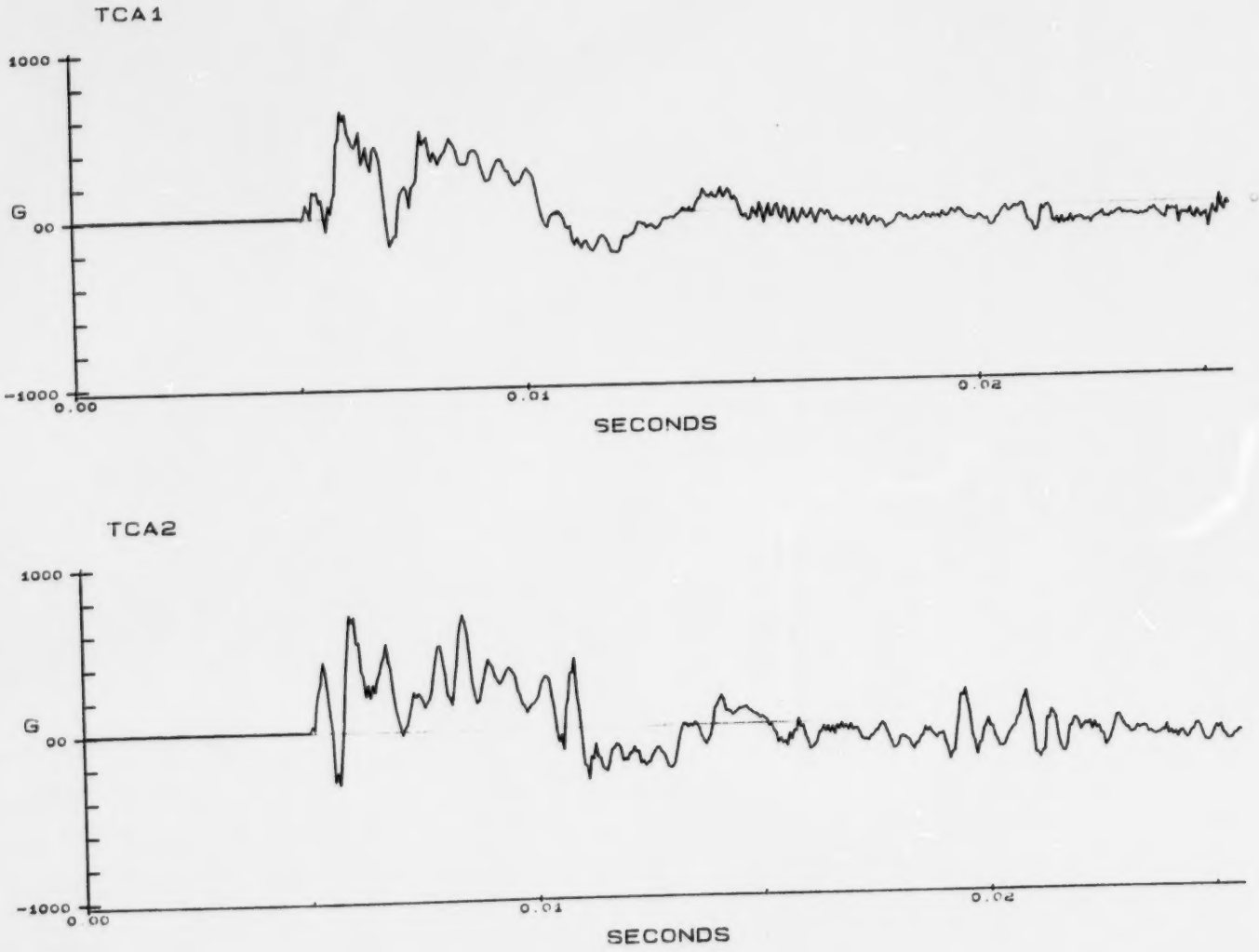


Figure 5: Accelerometer Traces for ¼ Scale Top Corner Drop Test (Model A)

QUARTER SCALE RFTP MODEL: B
FLAT SIDE DROP TEST

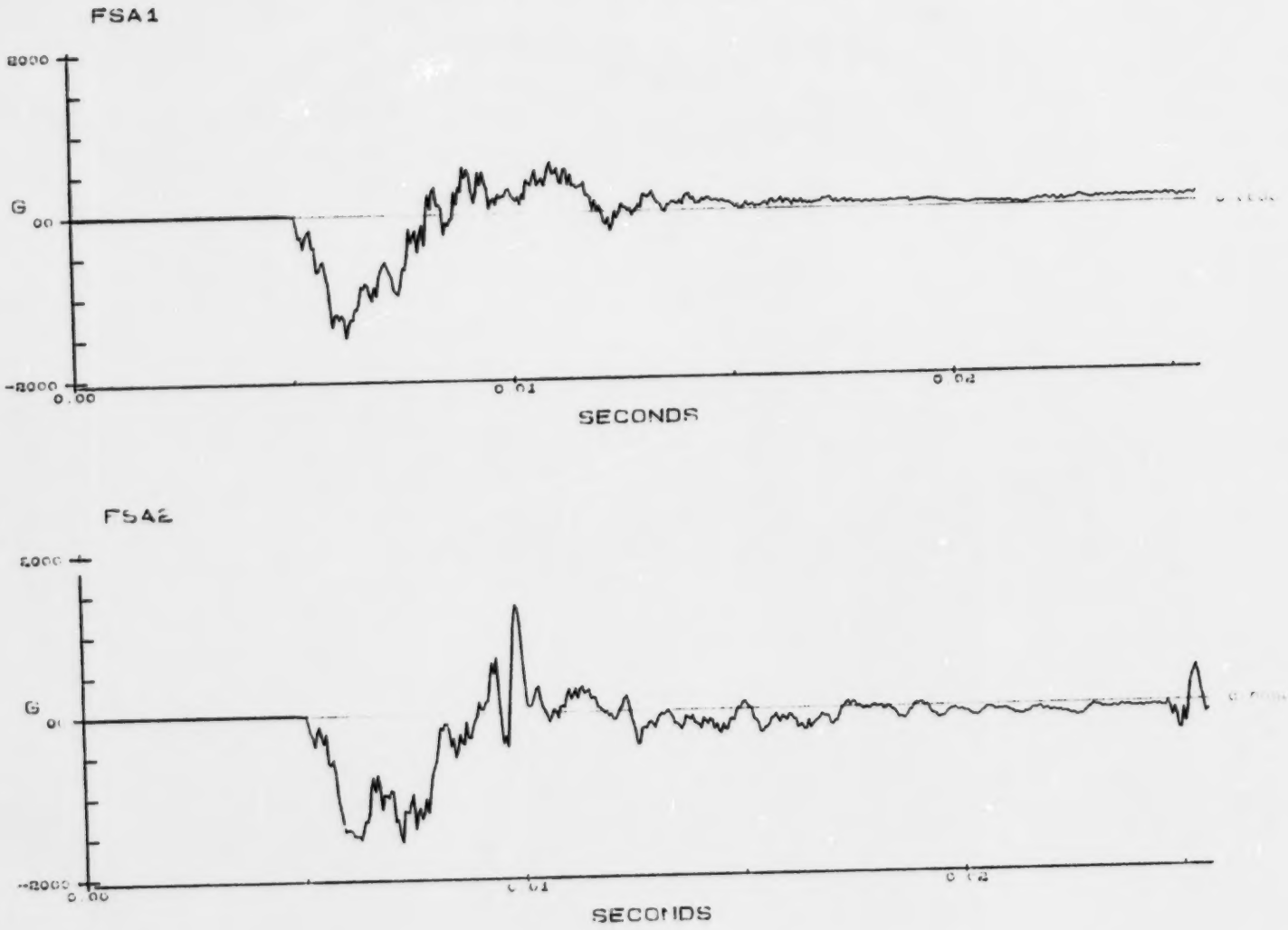


Figure 6: Accelerometer Traces for ¼ Scale Flat Side Drop Test (Model B)

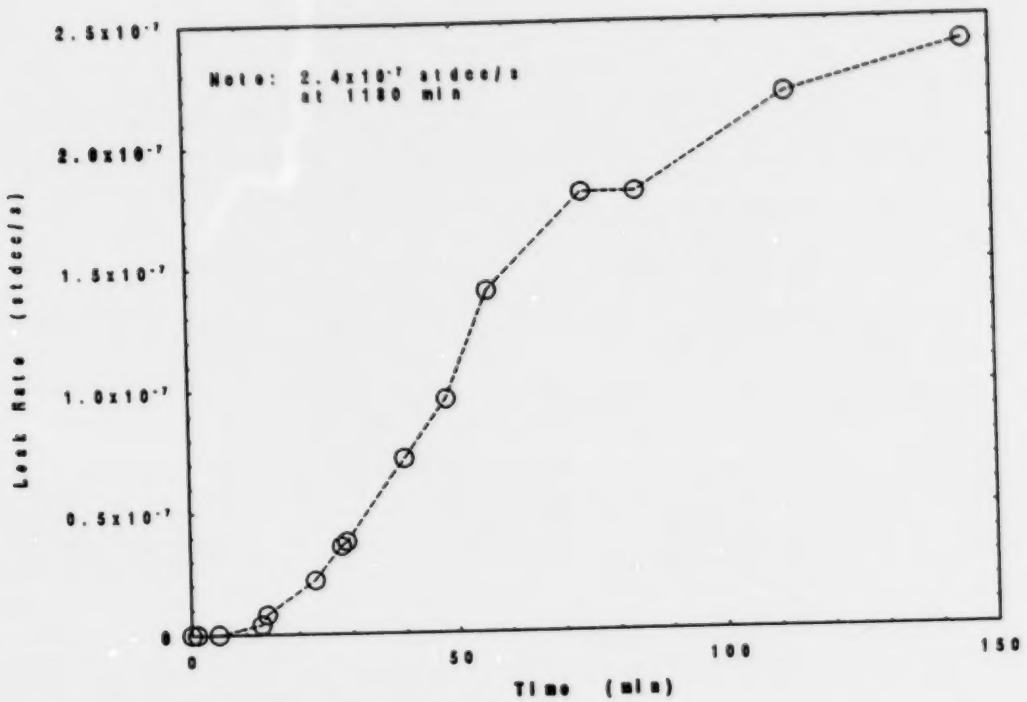


Figure 7: Leak Rate vs. Time for Pre-Drop Model A
(5 torr seal pressure differential)

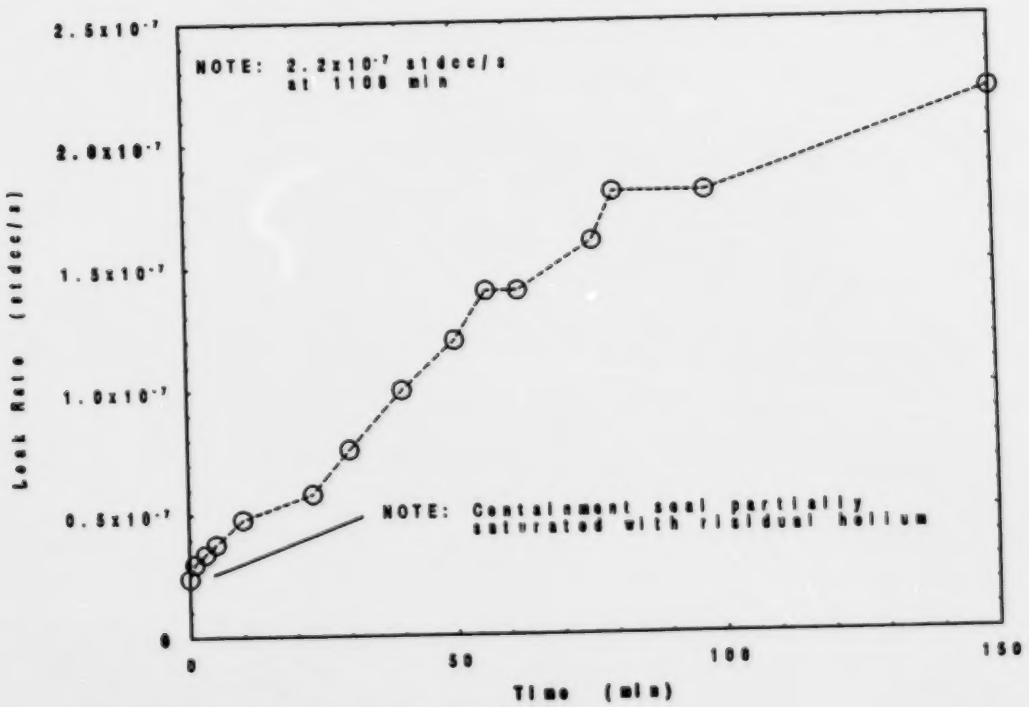


Figure 8: Leak Rate vs. Time for Post-Drop Model A
(5 torr seal pressure differential)

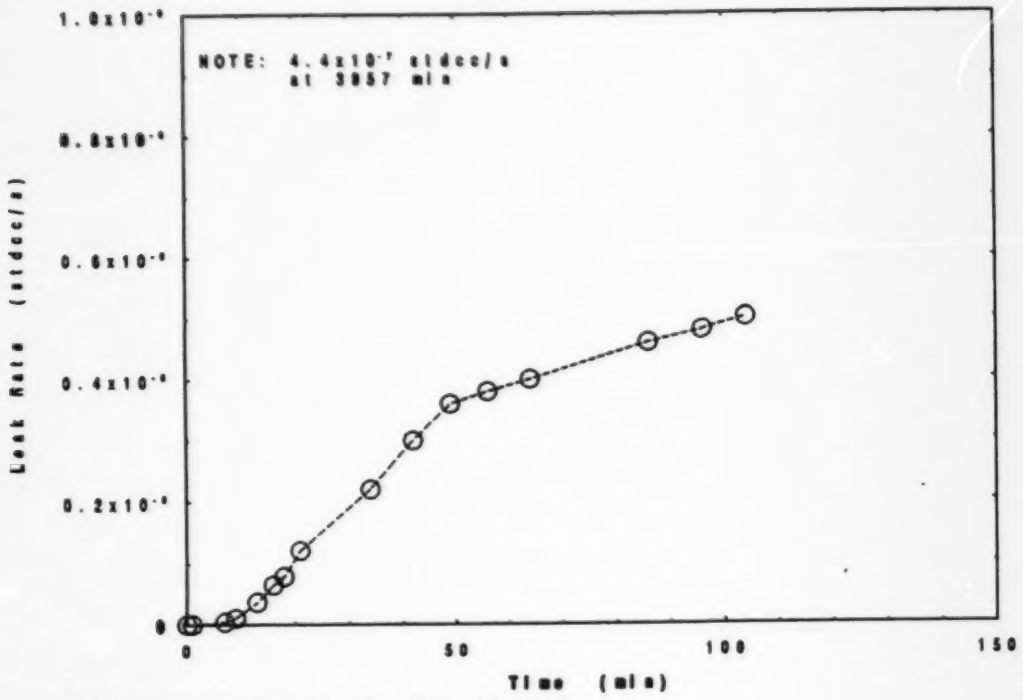


Figure 9: Leak Rate vs. Time for Pre-Drop Model B
(5 torr seal pressure differential)

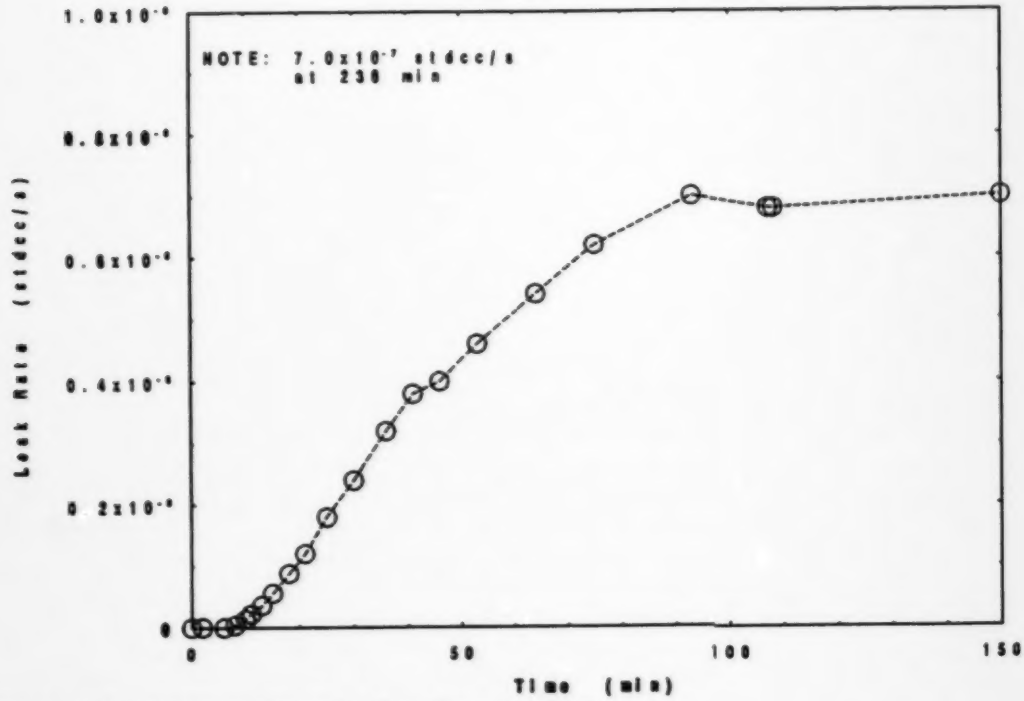


Figure 10: Leak Rate vs. Time for Post-Drop Model B
(5 torr seal pressure differential)

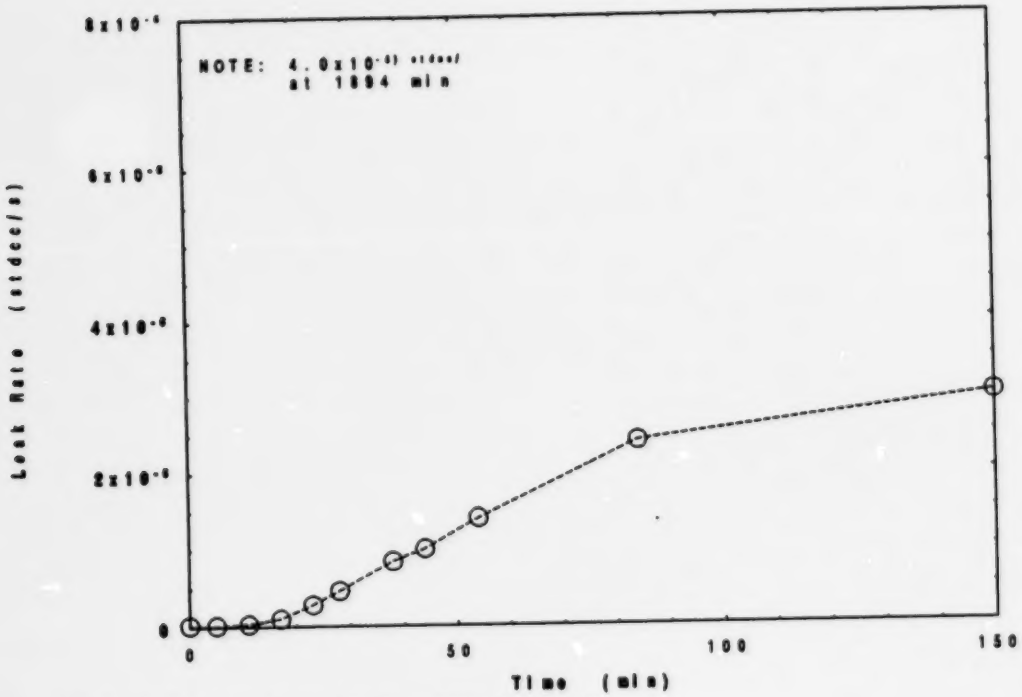


Figure 11: Leak Rate vs. Time for Post-Drop Model A (380 torr seal pressure differential)

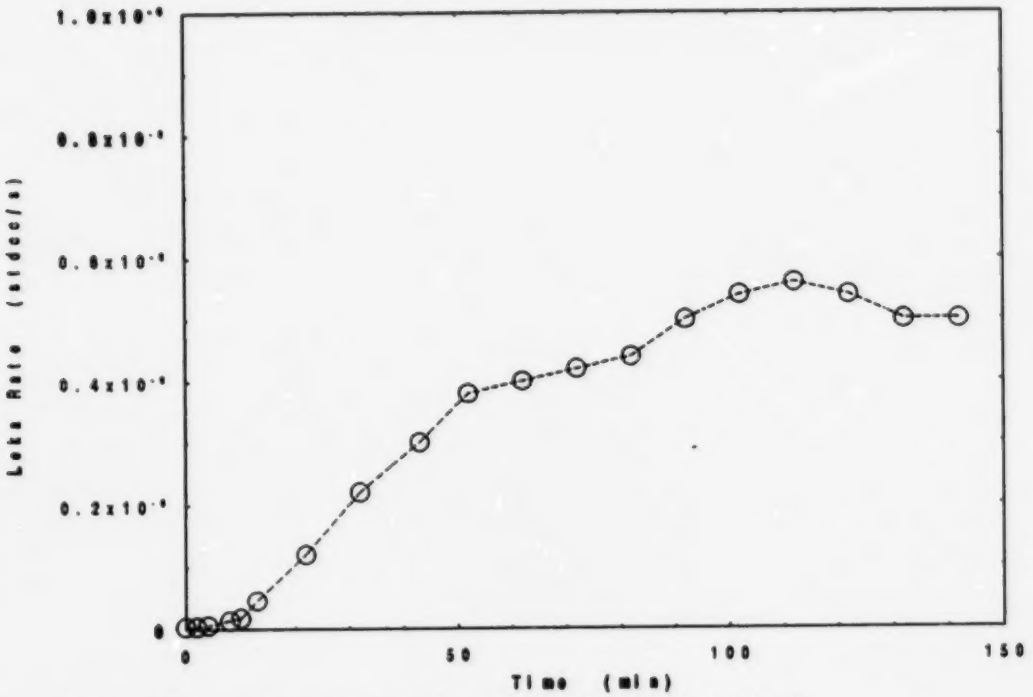


Figure 12: Leak Rate vs. Time for Post-Drop/Post-Disassembly Model B (5 torr seal pressure differential)

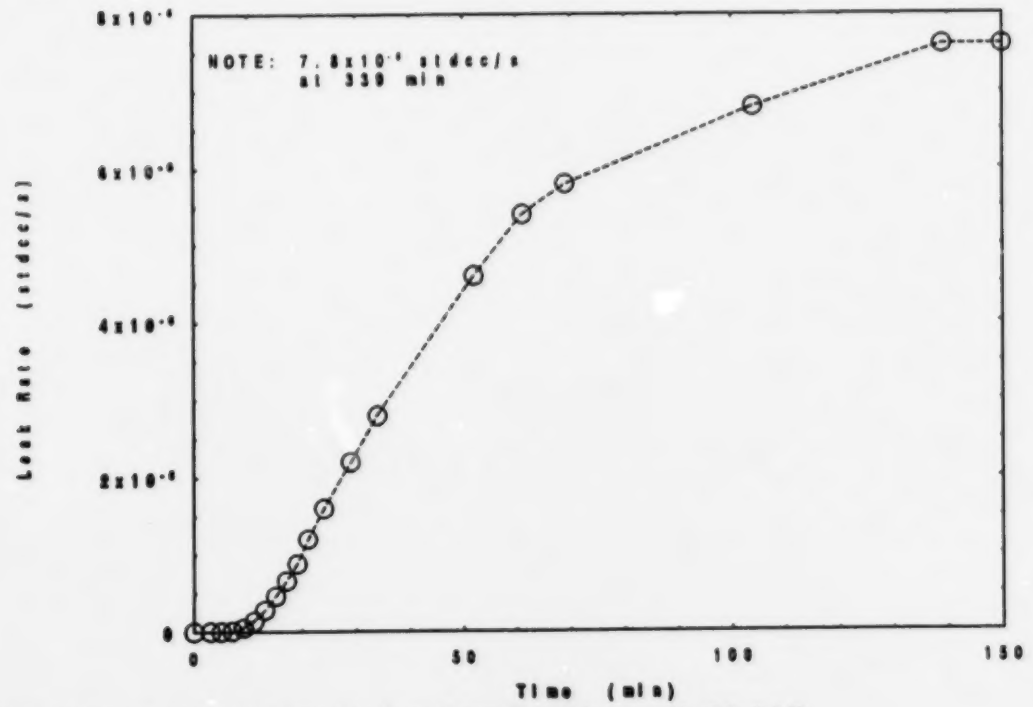
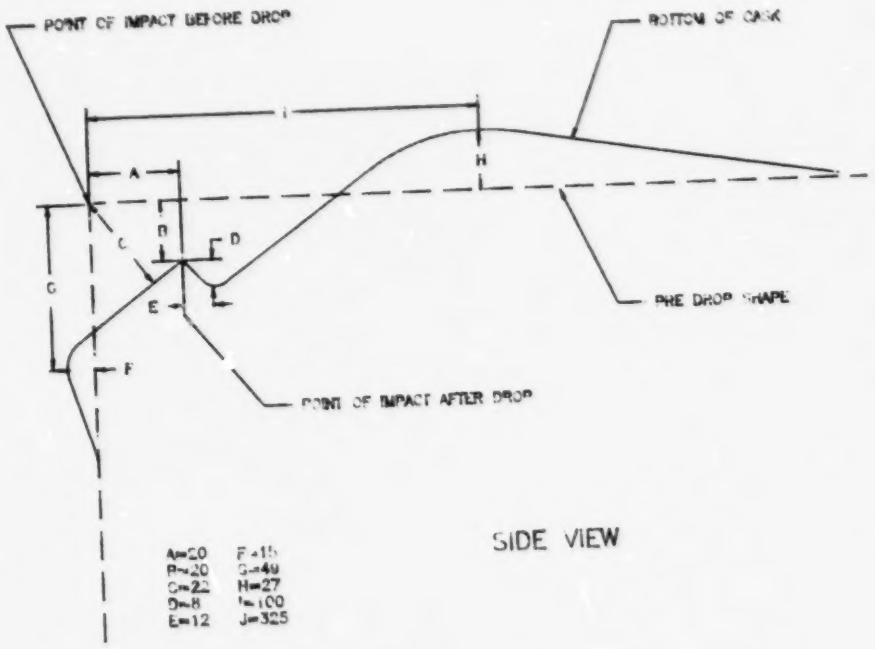
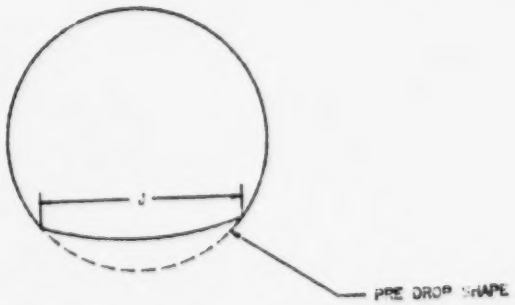


Figure 13: Leak Rate vs. Time for Post-Drop/Post Disassembly Model B (380 torr seal pressure differential)



SIDE VIEW

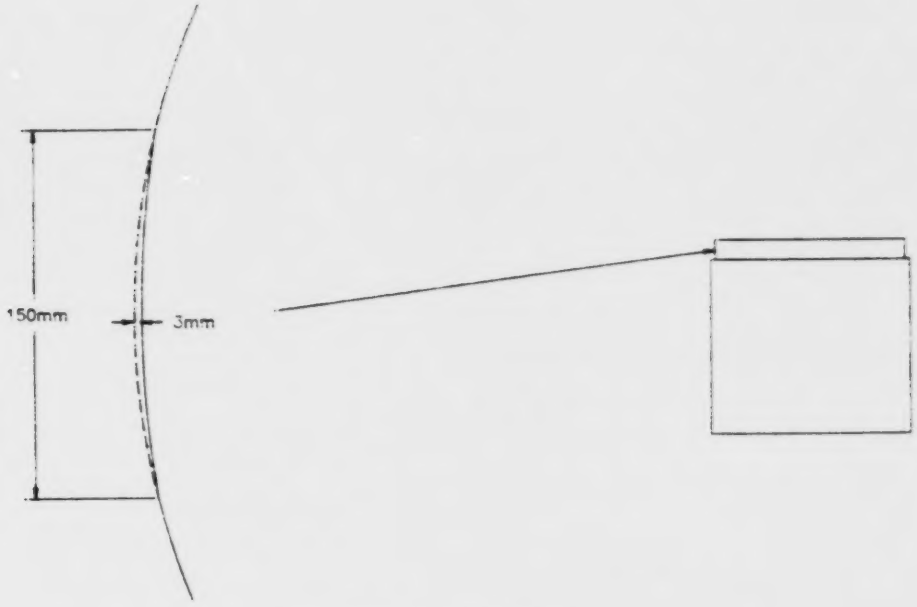


TOP VIEW

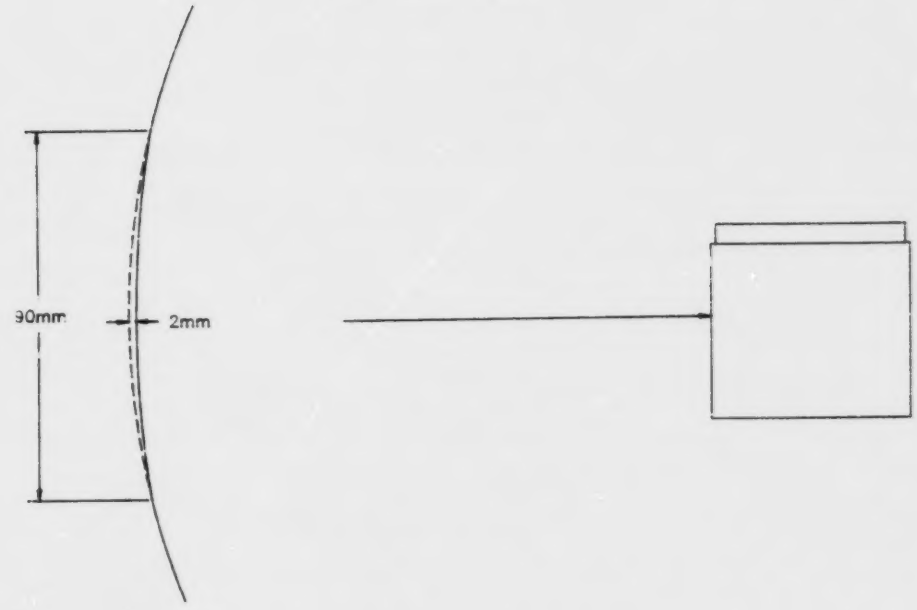
DEFORMATION NOT DRAWN TO SCALE

MODEL A DEFORMATION DATA AFTER TOP CORNER DROP TEST

FIGURE 14

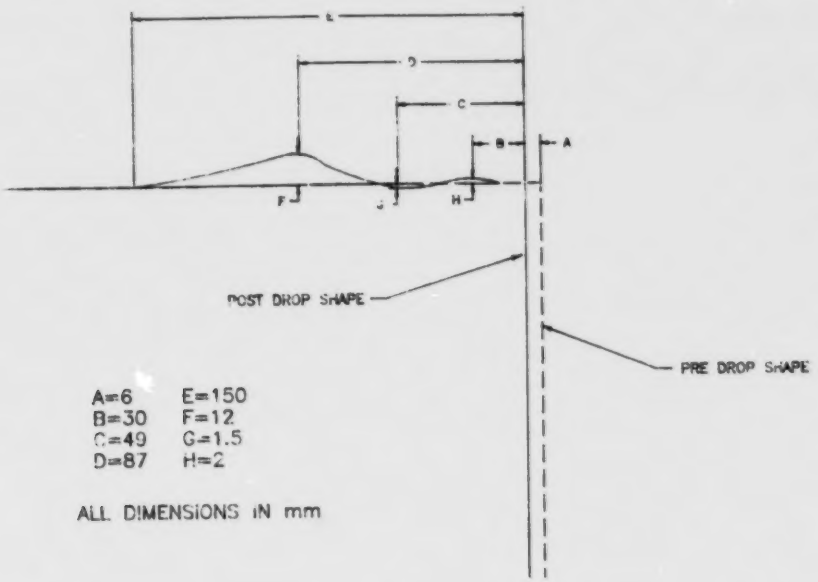


NOTE: DASHED LINES SHOW
PRE DROP SHAPE

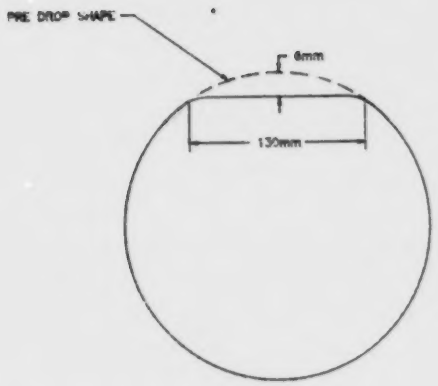


MODEL B OVERPACK BODY DEFORMATION DATA
AFTER FLAT SIDE DROP TEST

FIGURE 15



SIDE VIEW



TOP VIEW

DEFORMATION NOT
DRAWN TO SCALE

MODEL B OVERPACK LID
DEFORMATION DATA AFTER
FLAT SIDE DROP TEST

FIGURE 16

Appendix A: Leak Test Procedure and Apparatus

Leak Test Procedure and Apparatus

Both RFTP models were leak tested prior to and after each drop test. The test apparatus used to perform these tests had three major components: a vacuum bell jar, a leak detector and two mechanical roughing pumps. Figure 4 illustrates the test set-up with the various flow paths and leak detection points.

After the inner containers of the RFTP models had been prepared as per the approved test procedures (Appendix C), the container to be tested was placed in the centre of the bell jar base. The leak tested hoses were then attached to the container and to the fitting feeding through the bell jar wall. The bell jar square o-ring was cleaned with methanol using lint free wipes, as were the bell jar sealing surfaces. The bell jar top was lowered into position and roughing pump 1 (RP#1) was started in order to evacuate the jar. It took approximately 40 minutes to achieve an operational vacuum (less than 0.001 torr pressure).

During this time, roughing pump 2 (RP#2) was also started to evacuate the inner container. Once the bell jar and the inner container achieved approximate vacuum levels, the leak detector was connected at leak detector fitting 1 (LDF#1). Manual valve 6 (MV#6) was opened and MV#7 closed, after which RP#1 was turned off. At this point the helium content of the bell jar was monitored. When this value was 0×10^{-8} std cc/sec, a good background level to start from, helium was introduced into the inner container. First MV#3 was shut and RP#2 turned off. MV#5 was then opened and the inner container was backfilled to nominally 380 torr, as measured by TCG#2 and P#1 (originally only TCG#2 was used but later a new capacitance based manometer P#1 was received and put in line as shown in Figure 4). The leak detector then monitored the helium escaping into the bell jar as a function of time.

The bell jar used in the apparatus was custom made by High Vacuum Systems . It was composed of two parts, a cover and a base plate. The cover stood 1.3 m (50 in) tall and was 1.2 m (46 in) in diameter. It was constructed of stainless steel with a domed spherical top. The base was made of mild steel and had a feed-through passing under the sealing surface. This allowed access to the inside of the evacuated lid when it was positioned in place. There were also a number of feedthroughs at various locations on the bell jar lid. The assembled bell jar utilized a neoprene gasket to create a suitable seal exhibiting a leak rate of less than 1×10^{-10} std cc/sec of helium.

All welded joints in the vacuum hoses and custom made fittings were leak tested to give no detectable leak (ie less than 1×10^{-10} std cc/sec of helium). All "quick connect" fittings in the plumbing were made using one of the following type of connections:

- CAJON VCR with disposable copper gaskets exhibiting leak rates better than 4.0×10^{-9} std cc/sec. These fittings come equipped with leak testing ports.

- NW 25 and NW 40 ISO KF flanges with Viton o-rings.

- 1 1/8" diameter standard leak detector port compression seal fitting using viton o-rings.

These quick connect fittings were always leak checked after connections were made to ensure that there was no detectable leak (ie less than 2×10^{-9} std cc/sec). This was the only function of LDF#2.

The valves used in the apparatus were one of the following types of manually operated bellows valves:

- NUPRO series 8b exhibiting leak rates less than 4×10^{-9} std cc/sec.

- VARIAN NW25 and NW40 aluminum block vales exhibiting leak rates less than 2×10^{-10} std cc/sec.

These valves were also leak tested after they were connected in place.

The helium detector used was a VARIAN PORTA-TEST 938-41 leak detector capable of measuring helium leak rates in the range of 2×10^{-10} to 1×10^{-3} std cc/sec. The detector was calibrated prior to each test using one of the following certified calibration standards:

- LDS model SC-5 6.05×10^{-5} std cc/sec

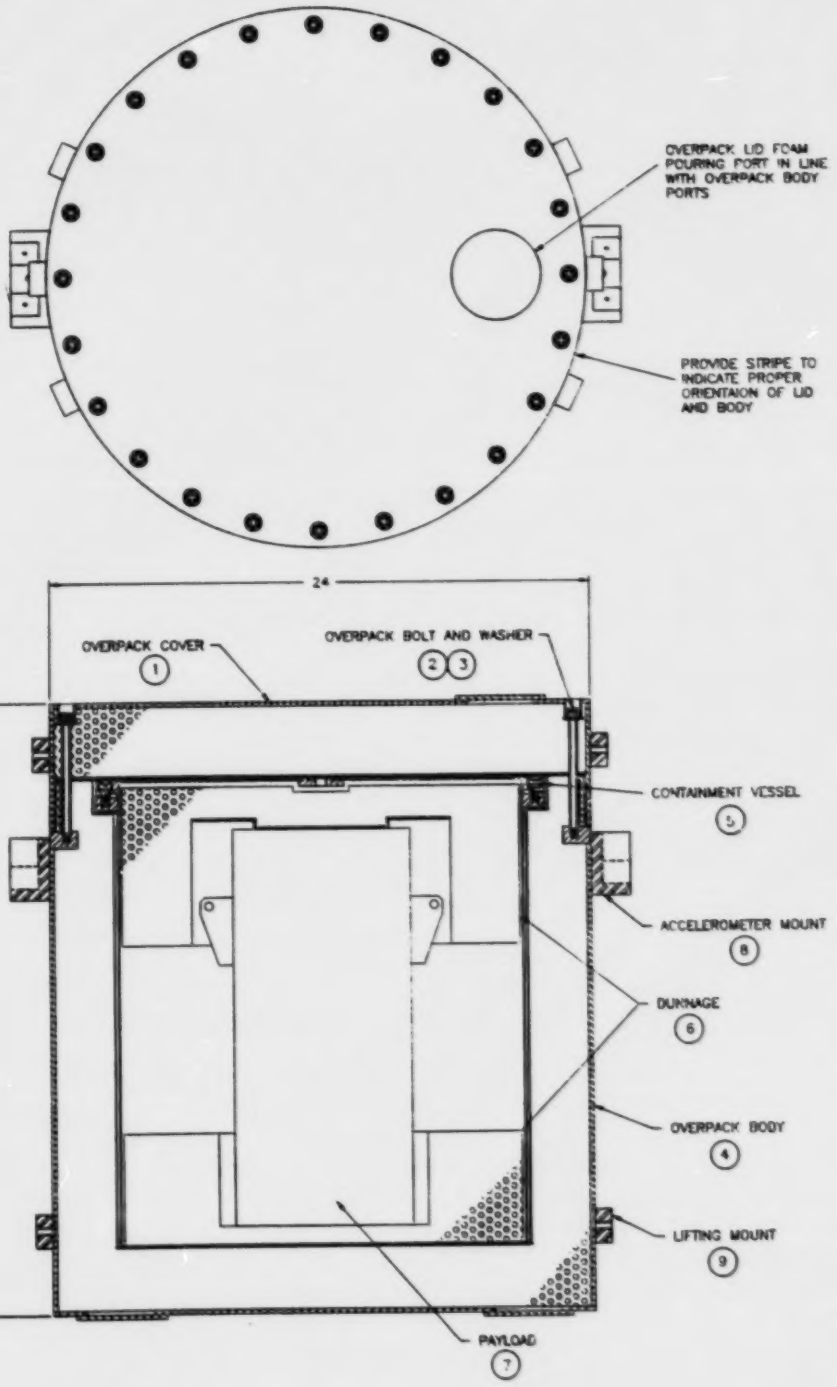
- VARIAN model 0981-F8473-302 5.5×10^{-8} std cc/sec

The helium gas supply port was connected to a helium gas bottle using 1/4" flexible tygon tubing and 1/4" Swagelok fittings. The helium pressure was regulated using a Matheson model 81 580 two stage gas bottle regulator (PRV#1)

The roughing pump used to evacuate the bell jar was a VARIAN SD-1400, 2 stage mechanical rotary vane pump with a free air displacement of 50 cfm (RP#1). The roughing pump used to evacuate the inner containers of the RFTP models was also a 2 stage mechanical rotary vane pump made by VARIAN, model SD-700, with a free air displacement of 27 cfm (RP#2).

Vacuum in the bell jar was monitored using a VARIAN model 0531 thermocouple gauge tube (TCG#1) calibrated as per manufacturers instructions. Vacuum and helium pressures in the inner containers of the RFTP models was monitored using both a VARIAN model 0531 thermocouple gauge tube (TCG#2) and a calibrated traceable MKS Baratron model 127 capacitance manometer (P#1).

Appendix B: 1/4 Scale Model Drawings



FINAL MODEL ASSEMBLY

SCALE 1" = 5"

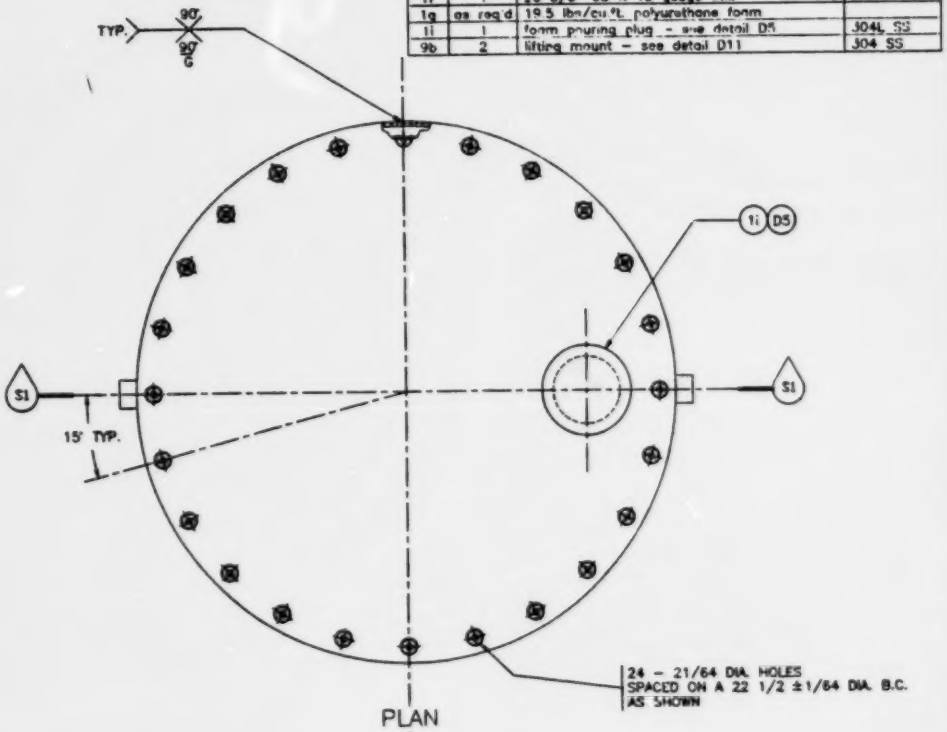
NOTE
ALL DIMENSIONS ARE IN INCHES

Ontario Hydro
research division
applied mechanics

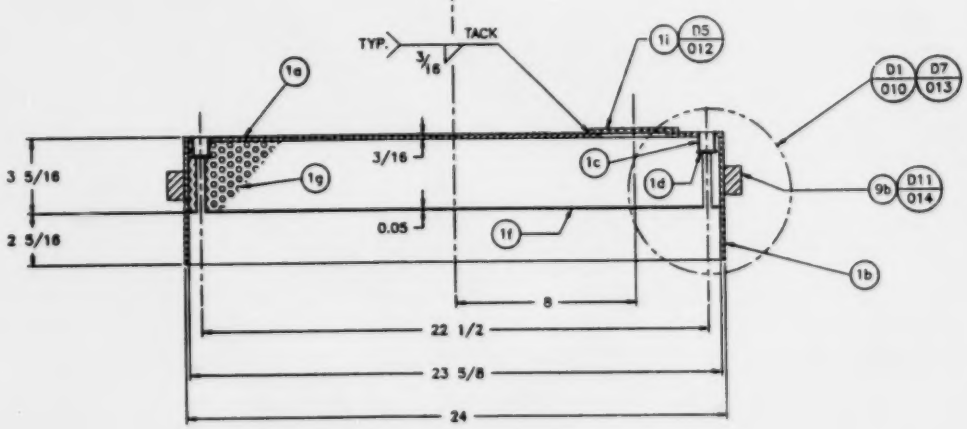
1/4 SCALE MODEL RADIOACTIVE FILTER TRANSPORTAION PACKAGE ASSEMBLY

designed by	approved by
C.N. / J.H.	
date DEC. 8, 1989	draftsman C. NAUMENKO
scale 1:5	dwg no 001 rev 02

BILL OF MATERIAL			
ITEM	QUANTITY	DESCRIPTION	MATERIAL
1a	1	24" OD X 3/16" thk.	304L SS
1b	1	24" OD X 3/16" thk. X 5 7/16" high	304L SS
1c	24	3/4" OD X 13/16" high X 18 gauge thk.	304L SS
1d	24	7/8" OD X 21/64" ID X 13 gauge thk.	304L SS
1f	1	23 5/8" OD X 18 gauge thk.	304L SS
1g	as req'd	19.5 lbs/cu.ft. polyurethane foam	
1i	1	foam pouring plug - see detail D5	304L SS
9b	2	lifting mount - see detail D11	304 SS



PLAN



S1

ITEM 1: OVERPACK COVER

SCALE 1" = 5"

NOTE
ALL GAUGES ARE U.S. STANDARD FOR STAINLESS STEEL SHEETS

NOTE
ALL DIMENSIONS ARE IN INCHES

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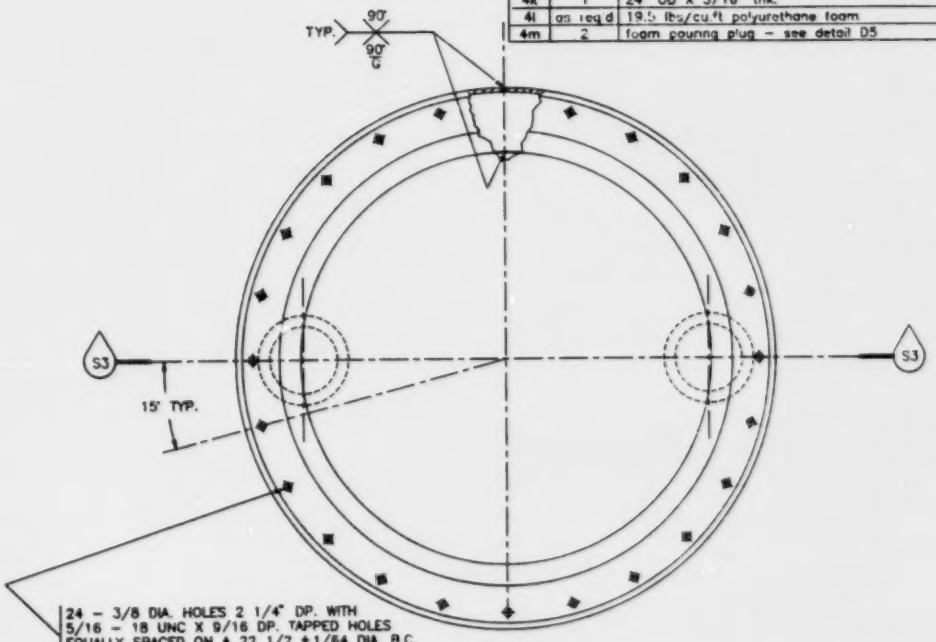
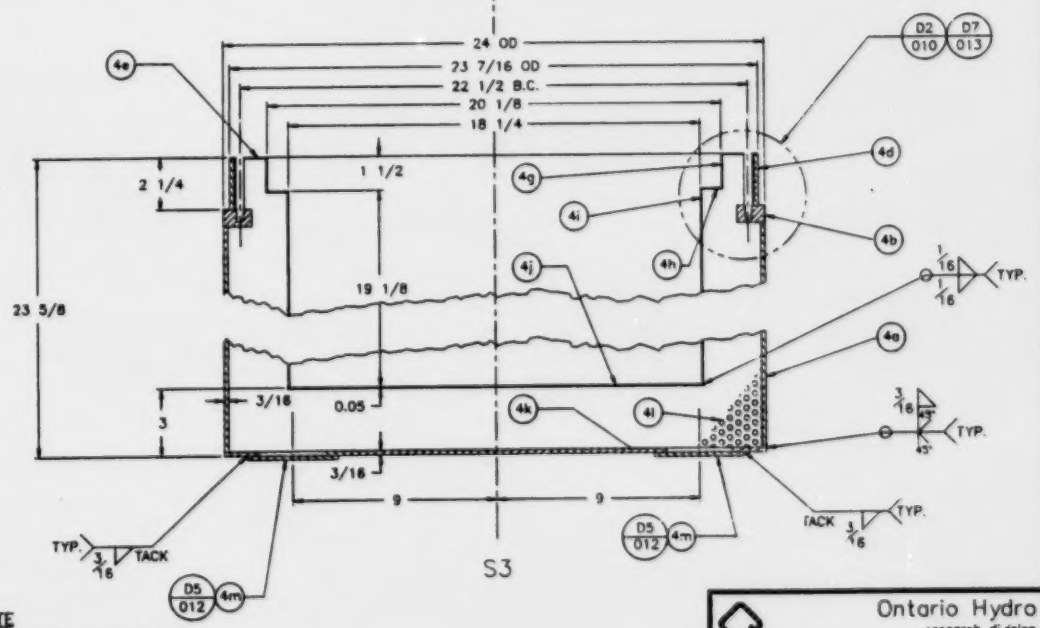
1/4 SCALE MODEL RADIOACTIVE FILTER TRANSPORTAION PACKAGE
SUB-ASSEMBLY DETAILS

designed by: C.N. / J.H.	approved by:	
date: DEC 8, 1989	draftsman: CY NAUMENKO	
scale: 1:5	dwg no: 002	rev: 02

BILL OF MATERIAL			
ITEM	QUANTITY	DESCRIPTION	MATERIAL
4a	1	24" OD X 3/16" thk. X 20 13/32" high	304L SS
4b	1	24" OD X 21 1/2" ID X 3/4" high	304L SS
4d	1	23 7/16" OD X 3/16" thk X 2 13/64 high	304L SS
4e	1	23 11/32" OD X 20 1/8" ID X 18 gauge	304L SS
4g	1	20 1/8" ID X 1.419" high X 18 gauge	304L SS
4h	1	18 1/4" ID X 20 3/8" OD X 18 gauge	304L SS
4i	1	18 1/4" ID X 19 1/16" high X 18 gauge	304L SS
4j	1	18 1/2" OD X 18 gauge thk.	304L SS
4k	1	24" OD X 3/16" thk.	304L SS
4l	as req'd	19.5 lbs/cu.ft polyurethane foam	
4m	2	foam pouring plug - see detail D5	304L SS



PLAN



S3

NOTE
ACCELEROMETER MOUNTS AND LIFTING MOUNTS NOT SHOWN

NOTE
ALL GAUGES ARE U.S. STANDARD FOR STAINLESS STEEL SHEETS

NOTE
ALL DIMENSIONS ARE IN INCHES

ITEM 4: OVERPACK BODY

SCALE: 1" = 5"

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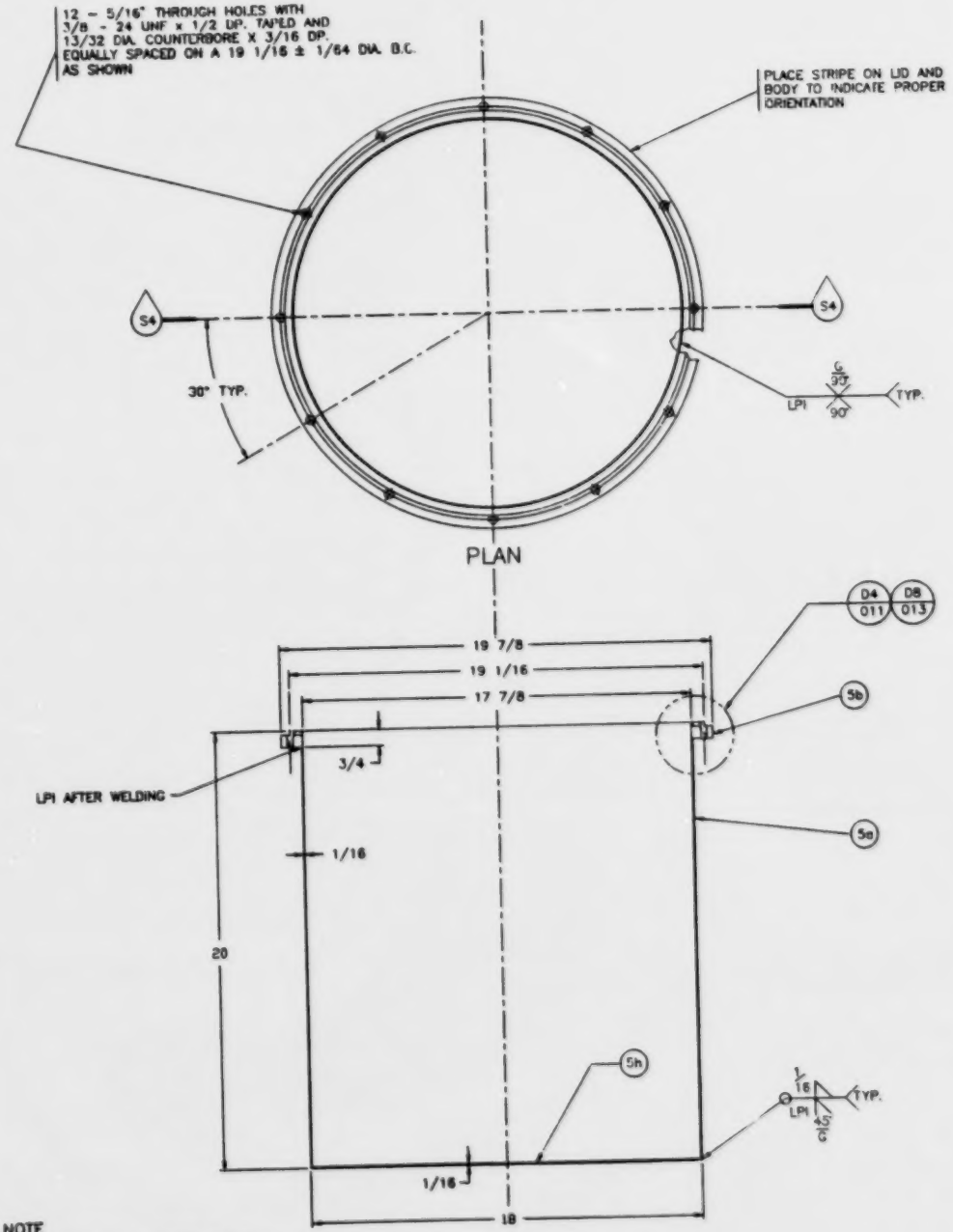
applied mechanics

1/4 SCALE MODEL RADIOACTIVE FILTER TRANSPORTAION PACKAGE SUB-ASSEMBLY DETAILS

designed by: C.N. / J.H.	approved by:
date: DEC 8, 1989	draftsman: CY NAUMENKO
scale: 1:5	dwg no: 003 rev: 02

BILL OF MATERIAL			
ITEM	QUANTITY	DESCRIPTION	MATERIAL
5a	1	18" OD X 19 3/16" nigh X 16 gauge thk.	304L SS
5b	1	19 7/8" OD X 17 7/8" ID X 3/4" nigh	304L SS
5h	1	18" OD X 16 gauge thk.	304L SS



NOTE
LPI ALL CONTAINMENT VESSEL WELDS

NOTE
HELIUM LEAK TEST ASSEMBLED VESSEL AT 3.7 PSIG.
PASS CRITERIA - 10^{-6} STD CC/SEC.
(INCLUDE WELDS)

NOTE
ALL GAUGES ARE U.S. STANDARD FOR STAINLESS STEEL

NOTE
ALL DIMENSIONS ARE IN INCHES

ITEM 5:
CONTAINMENT VESSEL BODY

SCALE 1" = 5"

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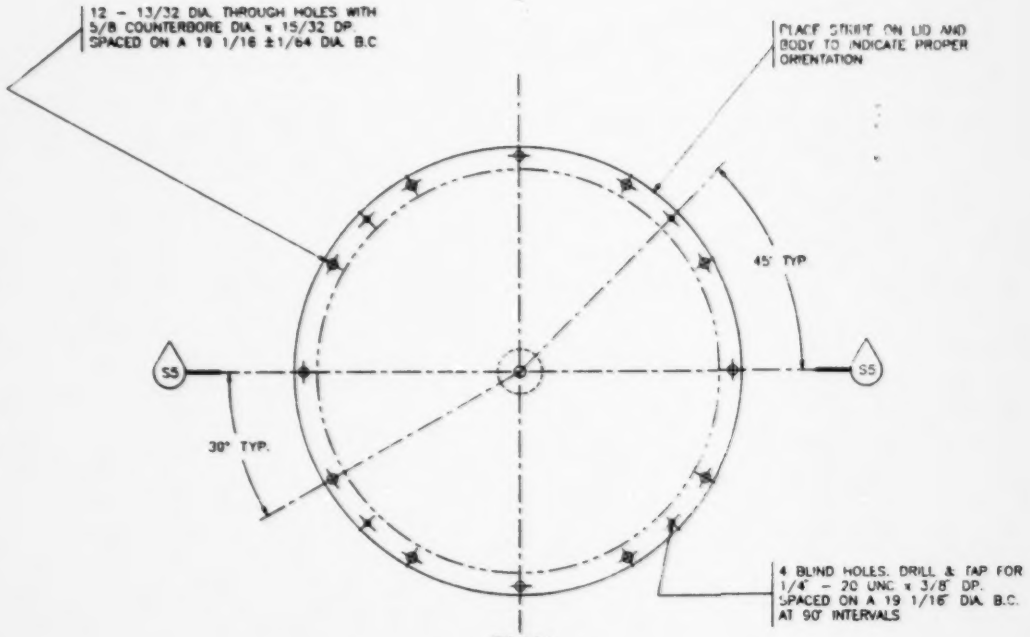
applied mechanics

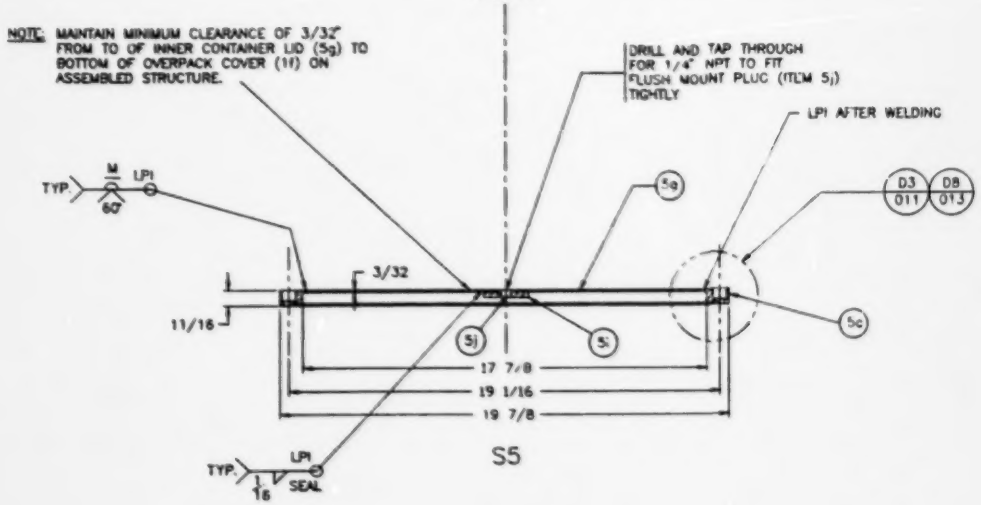
1/4 SCALE MODEL RADIOACTIVE FILTER TRANSPORTAION PACKAGE
SUB-ASSEMBLY DETAILS

designed by: C.N. / J.H.	approved by:
date: DEC 8, 1989	draftsman: CY NAUMENKO
scale: 1.5	dwg no: 004 rev: 02

BILL OF MATERIAL			
ITEM	QUANTITY	DESCRIPTION	MATERIAL
5c	1	19 7/8 OD x 17 5/8 ID x 11/16 thk.	304L SS
5g	1	17 5/8 OD x 13 gauge thk.	304L SS
5i	1	2" OD x 1/4" thk.	304L SS
5j	1	7/32 high x 1/4" NPT dia. flush mounted plug to fit tightly with hole	304L SS


12 - 13/32 DIA. THROUGH HOLES WITH 5/8 COUNTERBORE DIA. x 15/32 DP. SPACED ON A 19 1/16 ±1/64 DIA. B.C.
PLACE STRIPE ON LID AND BODY TO INDICATE PROPER ORIENTATION
45° TYP.
S5
S5
30° TYP.
4 BLIND HOLES. DRILL & TAP FOR 1/4" - 20 UNC x 3/8" DP. SPACED ON A 19 1/16" DIA. B.C. AT 90° INTERVALS

PLAN



S5

NOTE
LPI ALL CONTAINMENT VESSEL WELDS

NOTE
HELIUM LEAK TEST ASSEMBLED VESSEL AT 3.7 PSIG.
PASS CRITERIA - 10^{-8} STD CC/SEC.
(INCLUDE WELDS)

NOTE
ALL GAUGES ARE U.S. STANDARD FOR STAINLESS STEEL SHEETS

NOTE
ALL DIMENSIONS ARE IN INCHES

ITEM 5:

CONTAINMENT VESSEL LID

SCALE 1" = 5"

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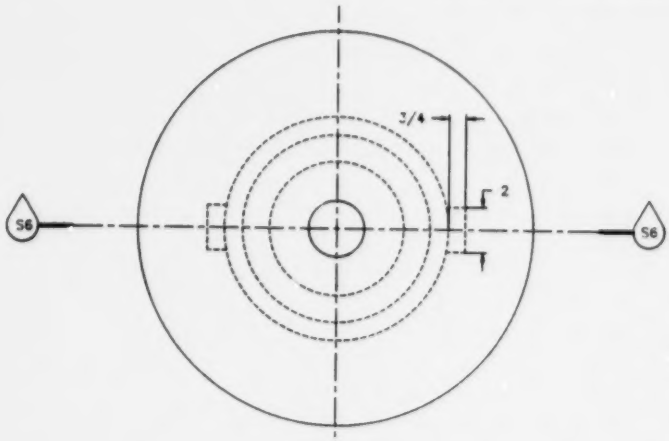
applied mechanics

1/4 SCALE MODEL RADIOACTIVE FILTER TRANSPORTAION PACKAGE SUB-ASSEMBLY DETAILS

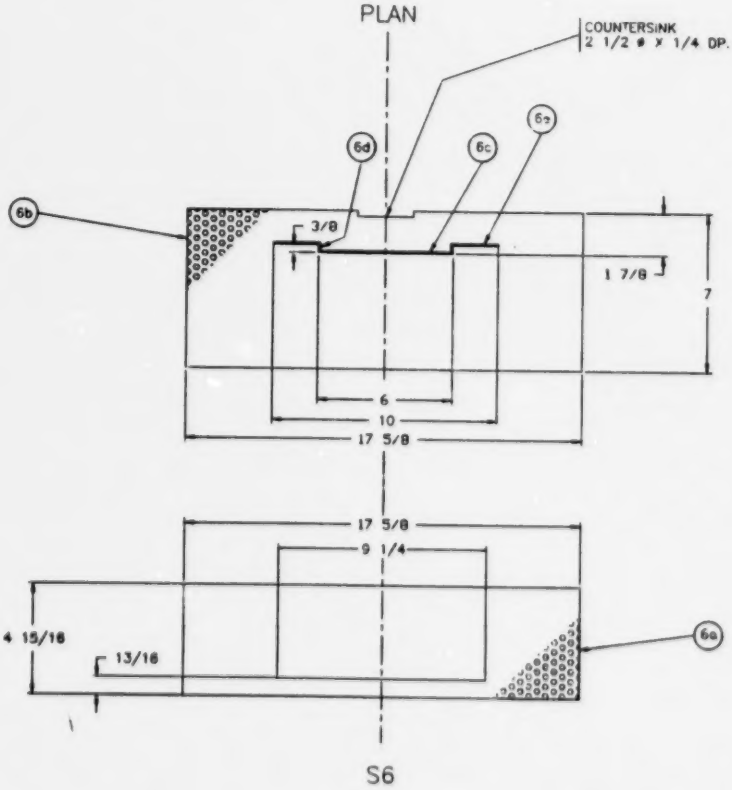
designed by: C.N. / J.H.	approved by:
date: DEC 8, 1989	draftsman: CY NAUMENKO
scale: 1:5	dwg no: 005 rev: 02A

BILL OF MATERIAL

ITEM	QUANTITY	DESCRIPTION	MATERIAL
6a	1	17.5 lbs/cu.ft polyurethane foam to shape	
6b	1	17.5 lbs/cu.ft polyurethane foam to shape	
6c	1	6" OD X 13 gauge thk.	304L SS
6d	1	6" OD X 1/4" nigh X 13 gauge thk.	304L SS
6e	1	10" OD X 6" ID X 13 gauge thk.	304L SS



PLAN



S6

ITEM 6: DUNNAGE

SCALE 1" = 5"

NOTE
ALL GAUGES ARE U.S. STANDARD FOR STAINLESS STEEL SHEETS

NOTE
ALL DIMENSIONS ARE IN INCHES

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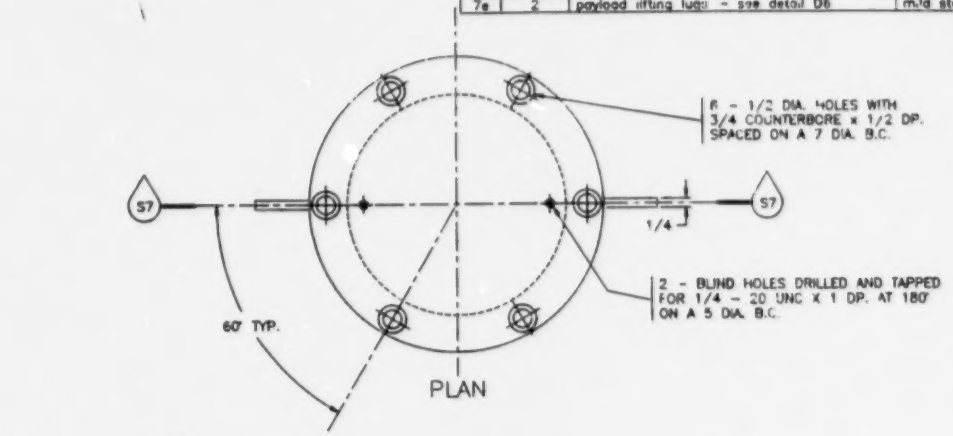
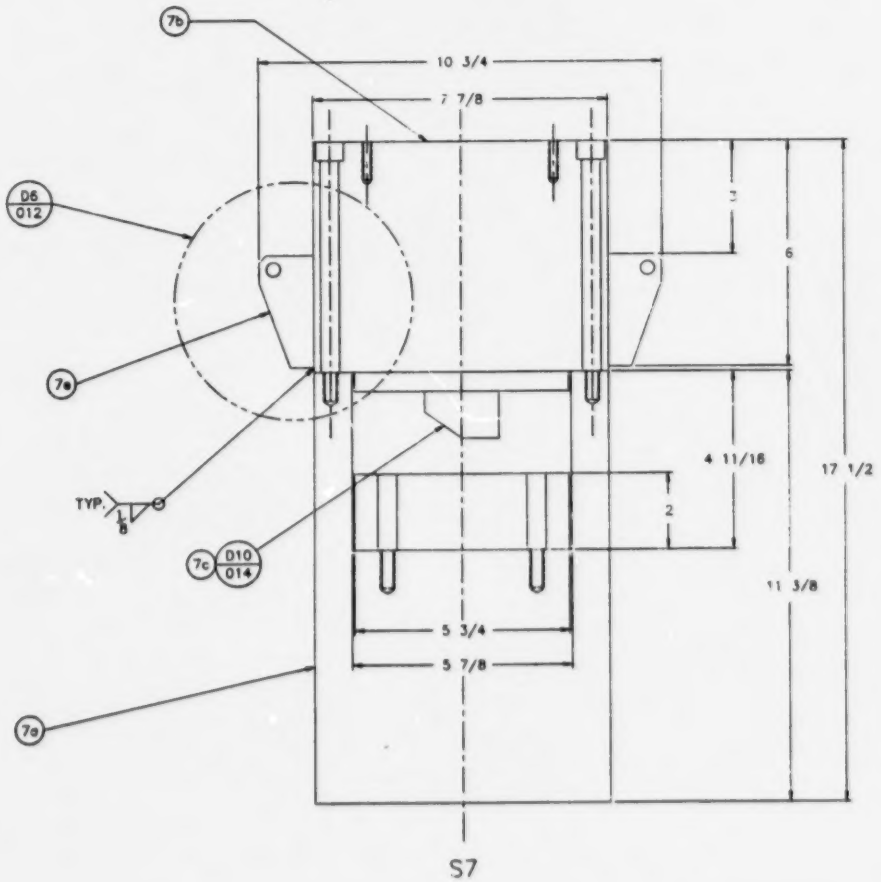
1/4 SCALE MODEL RADIOACTIVE FILTER TRANSPORTAION PACKAGE
SUB-ASSEMBLY DETAILS

designed by: C.N. / J.H.	approved by:
date: DEC. 8, 1989	draftsman: Cf NAUMENKO
scale: 1:5	dwg no: 006 rev: 03

BILL OF MATERIAL			
ITEM	QUANTITY	DESCRIPTION	MATERIAL
7a	1	lower payload mass section	mild steel
7b	1	upper payload mass section	mild steel
7c	1	accelerometer mount	mild steel
7d	1	bolts, 3/8" - 16 UNC X 6" shaft	as available
7e	2	payload lifting lugs - see detail D6	mild steel


8 - 1/2 DIA. HOLES WITH
3/4 COUNTERBORE x 1/2 DP.
SPACED ON A 7 DIA. B.C.
S7
S7
1/4
2 - BLIND HOLES DRILLED AND TAPPED
FOR 1/4 - 20 UNC X 1 DP. AT 180°
ON A 5 DIA. B.C.
60° TYP.
PLAN



ITEM 7: PAYLOAD

SCALE 1" = 5"

NOTE
TOTAL PAYLOAD ASSEMBLY MASS
= 230 LBS (92 KG) APPROX.

NOTE
ALL DIMENSIONS ARE IN INCHES

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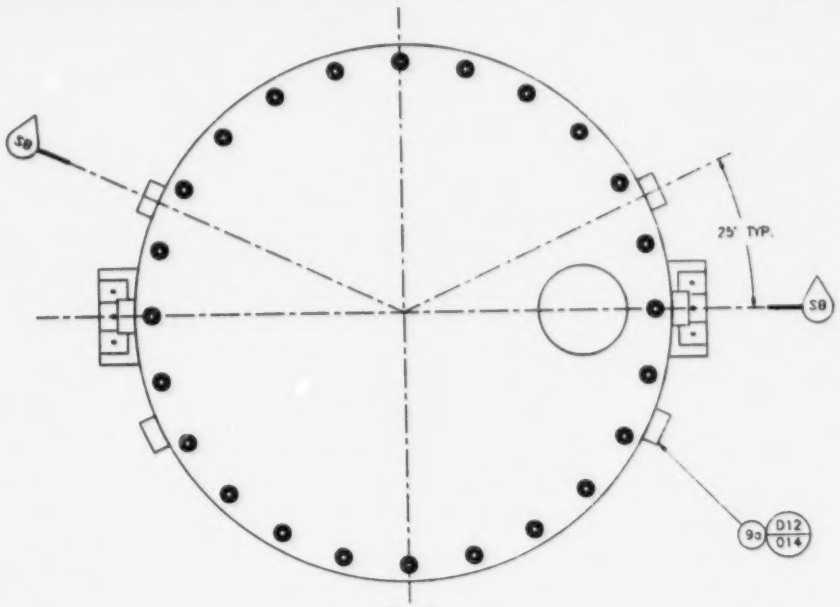
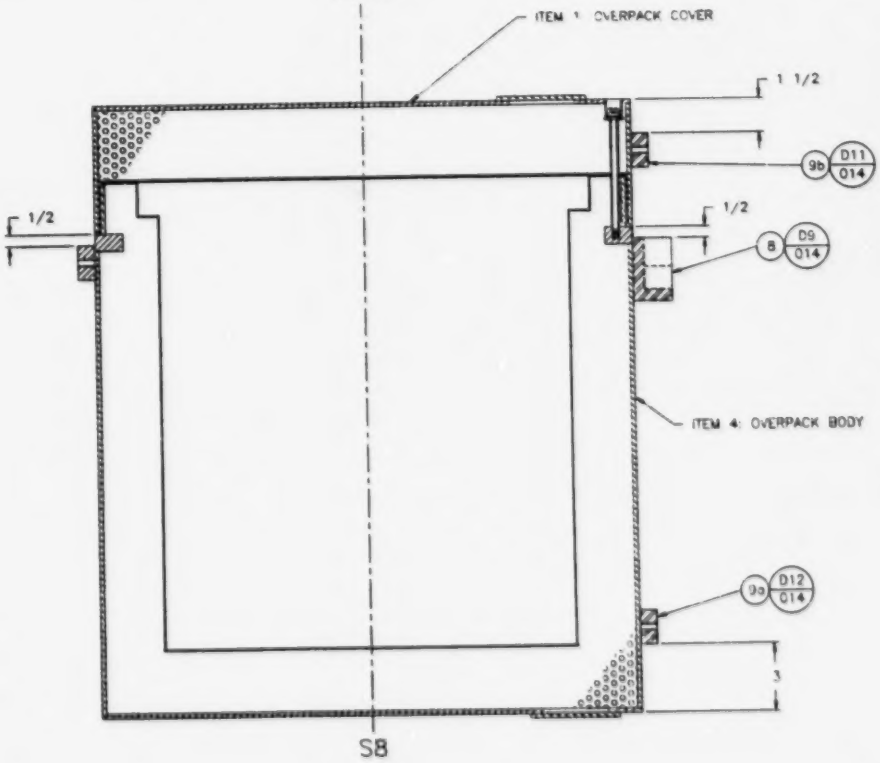
1/4 SCALE MODEL RADIOACTIVE
FILTER TRANSPORTAION PACKAGE
SUB-ASSEMBLY DETAILS

designed by: C.N. / J.H.	approved by:
date: DEC. 8, 1989	draftsman: CY NAUMENKO
scale: 1:5	dwg no: 007 rev: 02



PLAN



S8

COMPONENT LOCATION

SCALE: 1" = 5"

NOTE
ALL DIMENSIONS ARE IN INCHES

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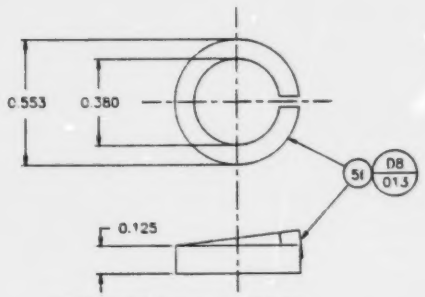
applied mechanics

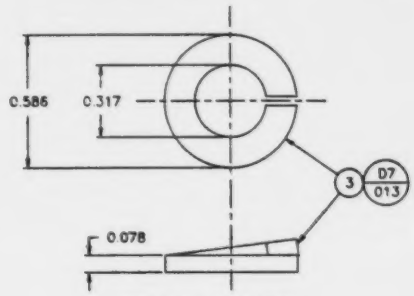
1/4 SCALE MODEL RADIOACTIVE FILTER TRANSPORTAION PACKAGE COMPONENT LOCATION

designed by:	approved by:
C.K. / J.H.	
date: DEC. 8, 1989	draftsman: Cf. NAUMENKO
scale: 1:5	dwg no: 008
rev: 03	

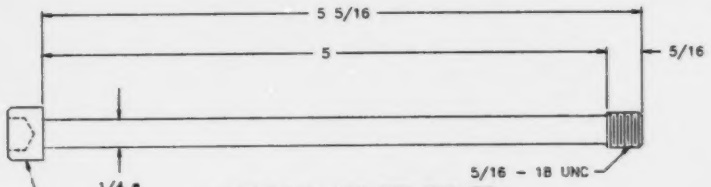
BILL OF MATERIAL			
	QUANTITY	DESCRIPTION	MATERIAL
	24	overpack cover bolt, 5/16 – 18 UNC	NITRONIC 60
	24	5/16" nominal helical spring lock washer	as available
5f	12	3/8" nominal hi-collar lock washer	as available
5e	12	containment vessel lid bolt, 3/8 – 24 UNF	NITRONIC 60



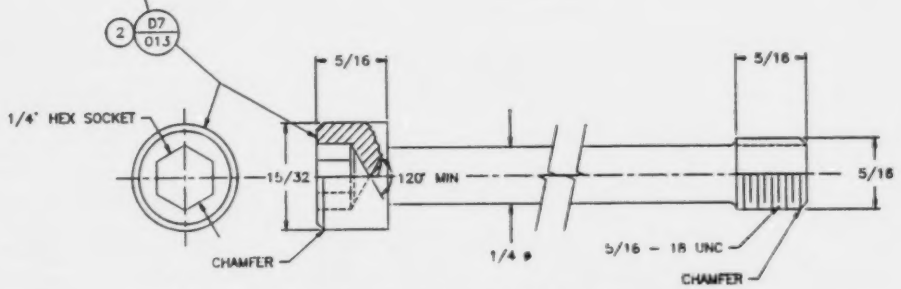
CONTAINMENT VESSEL
HI-COLLAR LOCK WASHER
SCALE 1" = 0.5"



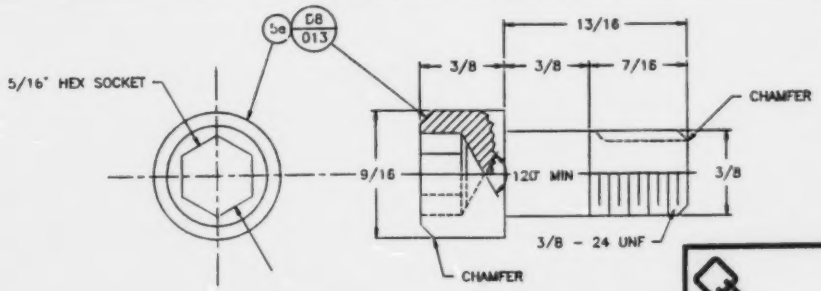
OVERPACK COVER
HELICAL SPRING LOCK WASHER
SCALE 1" = 0.5"



OVERPACK COVER BOLTS
SCALE 1" = 1"



OVERPACK COVER BOLTS (DETAIL)
SCALE 1" = 0.5"



CONTAINMENT VESSEL COVER BOLTS
SCALE: 1" = 0.5"

NOTE
ALL DIMENSIONS ARE IN INCHES

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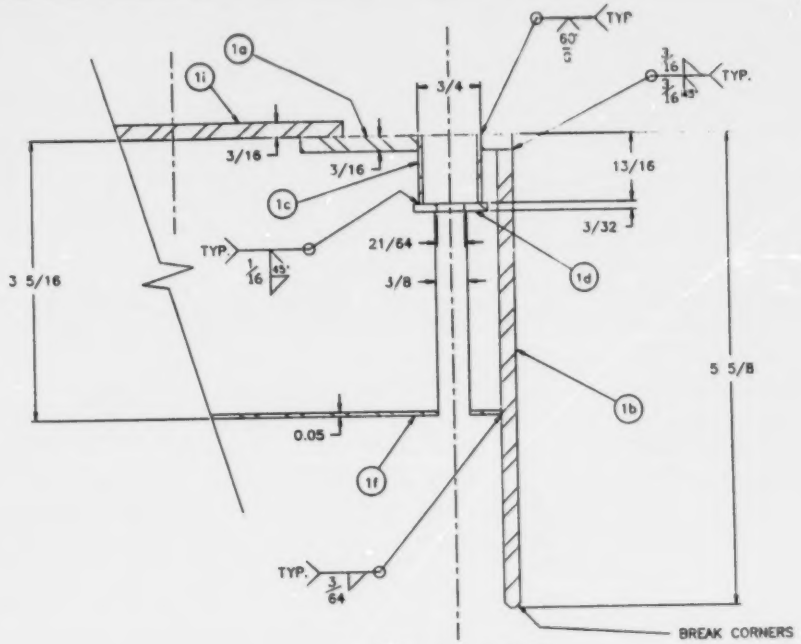
research division
applied mechanics

1/4 SCALE MODEL RADIOACTIVE FILTER TRANSPORTAION PACKAGE
DETAIL

designed by: C.N. / J.H.	approved by:
date DEC. 8, 1989	draftsman CY HAUSCHKO
scale AS SHOWN	dwg no 009 rev 02

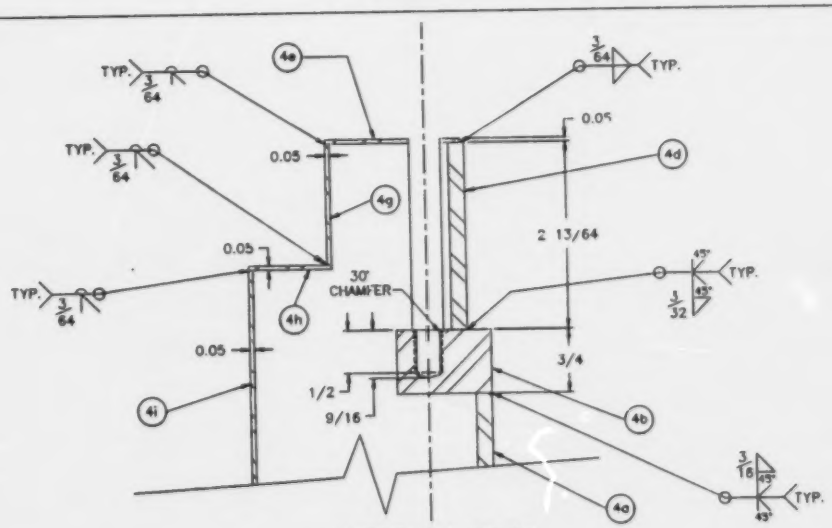


OVERPACK COVER

BOLTING CONFIGURATION DETAIL

SCALE: 1" = 1.33"

DETAIL D1



OVERPACK BODY

BOLTING CONFIGURATION DETAIL

SCALE: 1" = 1.33"

DETAIL D2

NOTE
ALL DIMENSIONS ARE IN INCHES

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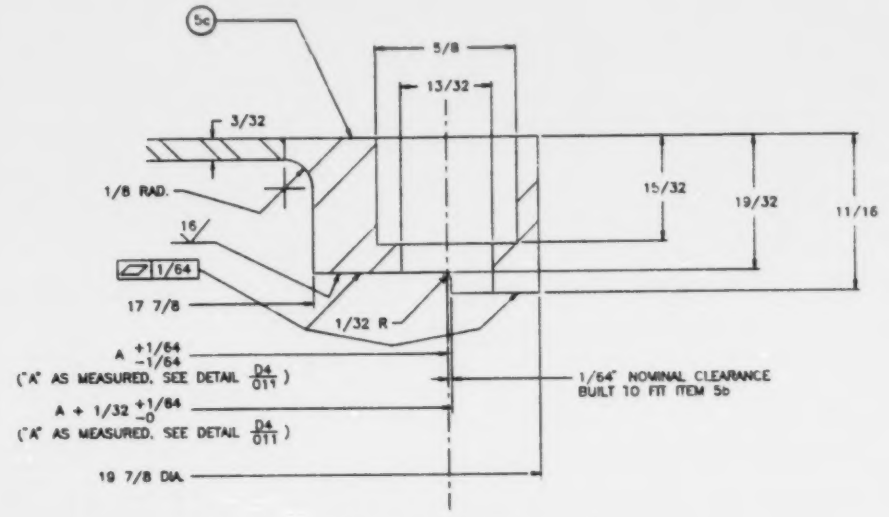
research division
applied mechanics

1/4 SCALE MODEL RADIOACTIVE FILTER TRANSPORTAION PACKAGE DETAIL

designed by: C.N. / J.H.	approved by:
date: DEC. 8. 1989	draftsman: CY NAUMENKO
scale: 3.4	dwg no: 010
	rev: 02

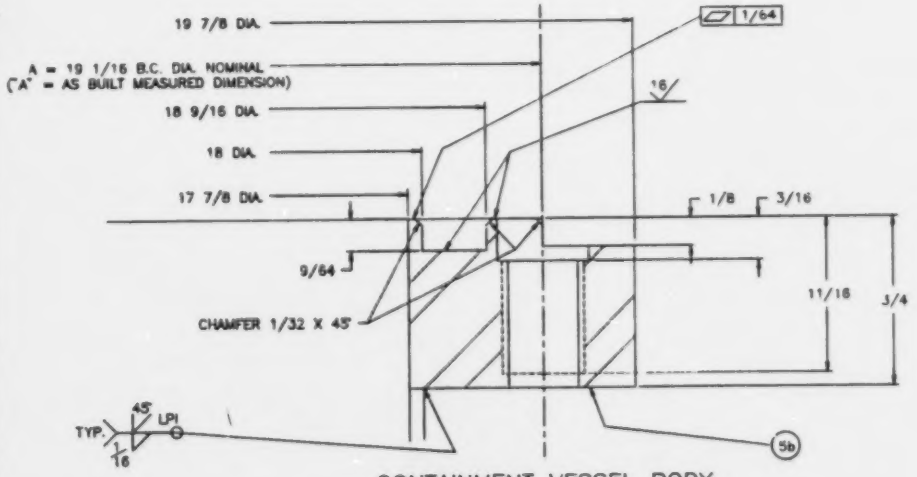


CONTAINMENT VESSEL LID

BOLTING FLANGE

SCALE 1" = 0"

DETAIL D3



CONTAINMENT VESSEL BODY

BOLTING FLANGE

SCALE 1" = 0"

DETAIL D4

NOTE
ALL DIMENSIONS ARE IN INCHES
EXCEPT SURFACE FINISH IN MICRO-INCHES

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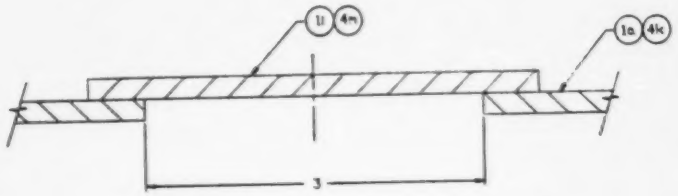
applied mechanics

1/4 SCALE MODEL RADIOACTIVE FILTER TRANSPORTAION PACKAGE DETAIL

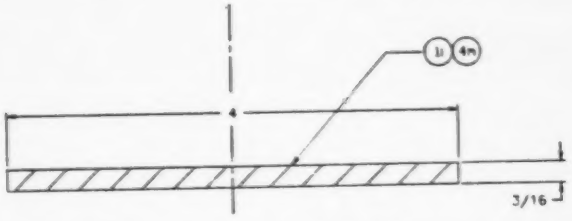
designed by	approved by
C.N. / J.H.	
date DEC. 8, 1989	draftsmen CY NAUMENKO
scale 2:1	dwg no 011 rev 02

BILL OF MATERIAL			
ITEM	QUANTITY	DESCRIPTION	MATERIAL
1, 4m	3	4" OD X 3/16 thk.	304L SS
7b	2	payload lifting flanges as shown	mild steel



FOAM POURING PORT PLUG ASSEMBLY

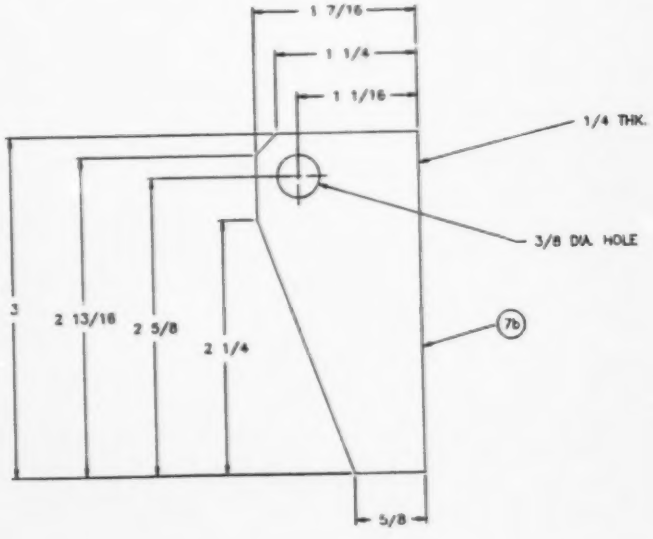
SCALE: 1" = 1"



FOAM POURING PORT PLUG

SCALE: 1" = 1"

DETAIL D5



PAYLOAD LIFTING LUG

SCALE: 1" = 1"

DETAIL D6

NOTE
ALL DIMENSIONS ARE IN INCHES

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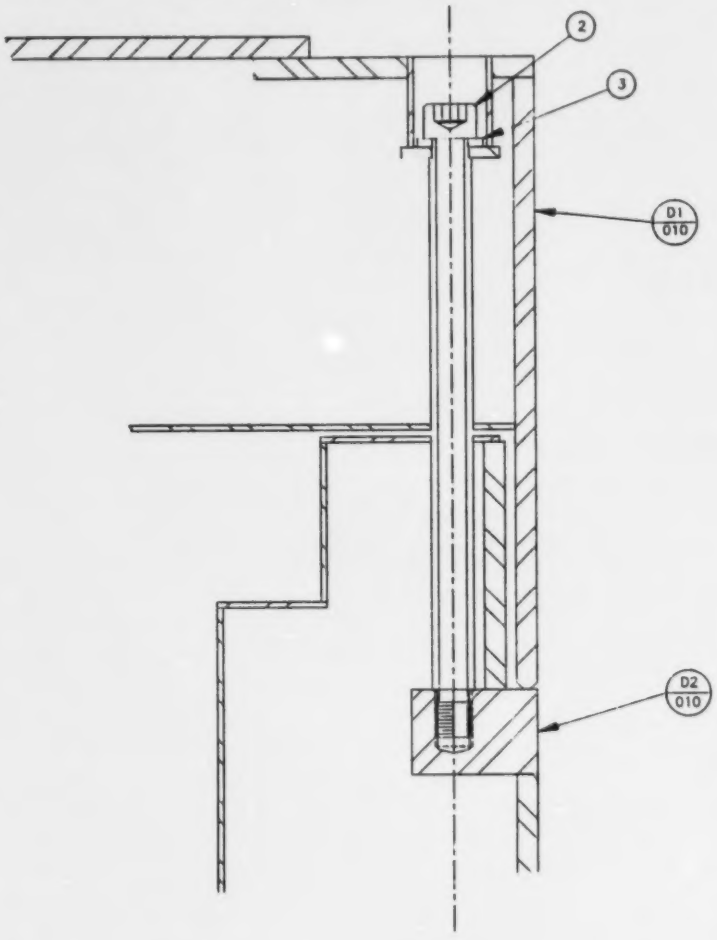
applied mechanics

1/4 SCALE MODEL RADIOACTIVE FILTER TRANSPORTAION PACKAGE DETAIL

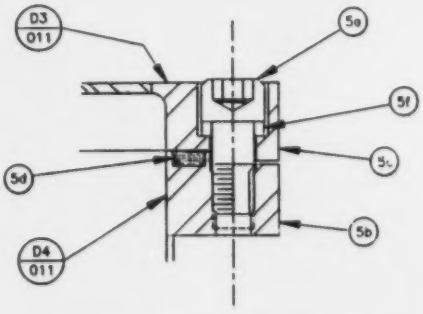
designed by	approved by:
C.H. / J.H.	
date DEC. 8, 1989	draftsmen CY NAUMENKO
scale 1:1	dwg no 012 rev 02



OVERPACK BOLTING ASSEMBLY

SCALE 1" = 1"

DETAIL D7



CONTAINMENT VESSEL ASSEMBLY

SCALE 1" = 1"

DETAIL D8

NOTE
ALL DIMENSIONS ARE IN INCHES

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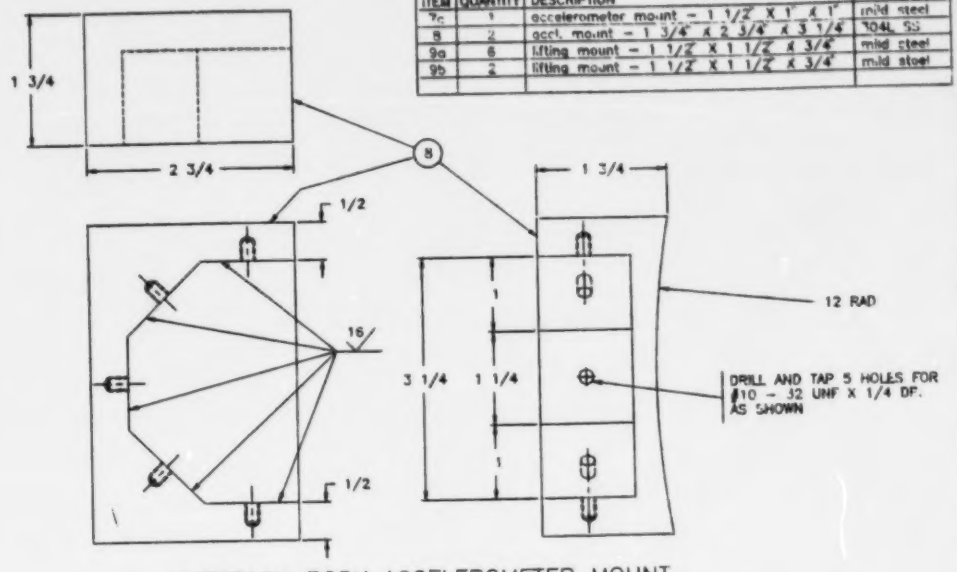
1/4 SCALE MODEL RADIOACTIVE FILTER TRANSPORTAION PACKAGE ASSEMBLY

designed by	approved by
C.H. / J.H.	
date DEC. 8. 1989	draftsman Cr. NAUMENKO
scale 1:1	dwg no 013	rev 02

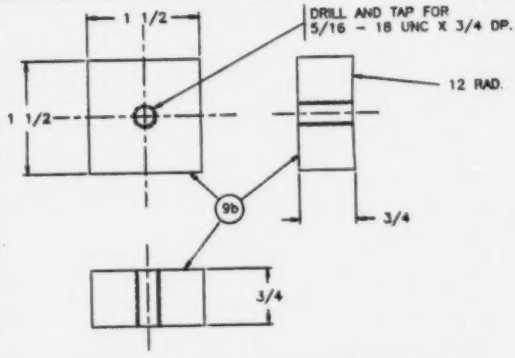
BILL OF MATERIAL			
ITEM	QUANTITY	DESCRIPTION	MATERIAL
7c	1	accelerometer mount - 1 1/2" X 1" X 1"	mild steel
8	2	accl. mount - 1 3/4" X 2 3/4" X 3 1/4"	304L SS
9a	6	lifting mount - 1 1/2" X 1 1/2" X 3/4"	mild steel
9b	2	lifting mount - 1 1/2" X 1 1/2" X 3/4"	mild steel



OVERPACK BODY ACCELEROMETER MOUNT

SCALE 1" = 1.5"

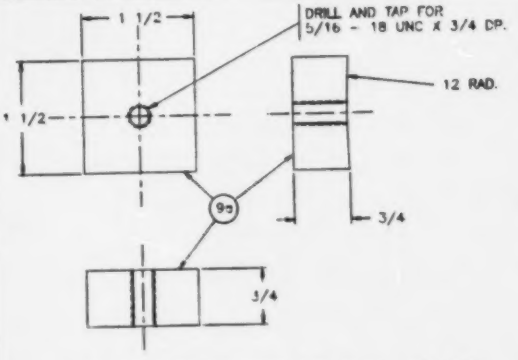
DETAIL D9



OVERPACK COVER LIFTING MOUNT

SCALE 1" = 1.5"

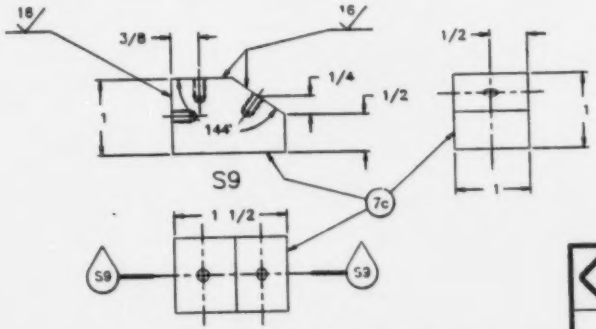
DETAIL D11



OVERPACK BODY LIFTING MOUNT

SCALE 1" = 1.5"

DETAIL D12



PAYLOAD ACCELEROMETER MOUNT

SCALE 1" = 1.5"

DETAIL D10

NOTE
ALL DIMENSIONS ARE IN INCHES

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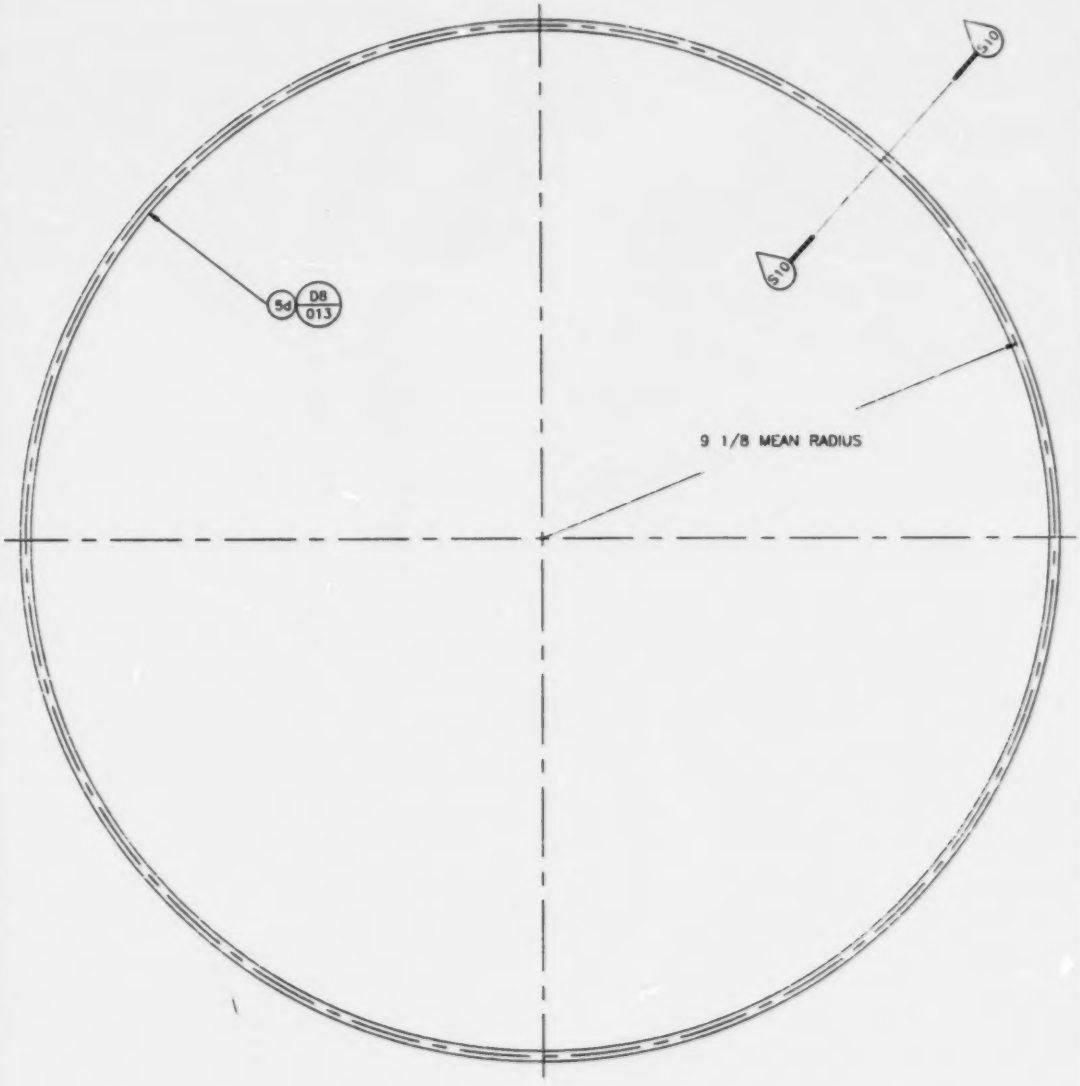
research division
applied mechanics

1/4 SCALE MODEL RADIOACTIVE FILTER TRANSPORTAION PACKAGE DETAIL

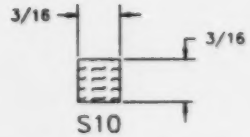
designed by	approved by
C.N. / J.H.	
date: DEC. 8, 1983	draftsman: Cf. NAUMENKO
scale: 2:3	dwg no: 014
rev: 02	

BILL OF MATERIAL			
ITEM	QUANTITY	DESCRIPTION	MATERIAL
5d	1	18 1/16" Ø x 18 7/16" OD x 3/16" square cross section	silicone rubber



CONTAINMENT VESSEL GASKET

SCALE 1" = 3"



GASKET CROSS-SECTION

SCALE 1" = 6"

NOTE
ALL DIMENSIONS ARE IN INCHES

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research division
applied mechanics

1/4 SCALE MODEL RADIOACTIVE FILTER TRANSPORTAION PACKAGE DETAIL

designed by: C.N. / J.H.	approved by:
date: DEC 8, 1989	draftsman: CY NAUMENKO
scale: AS SHOWN	dwg no: 015 rev: 02

Appendix C: Test Procedure: Drop Test of Two 1/4 Scale RFTP Models

DATE: January 31, 1990
FILE: RMTU Memo No. 096
907-TRAN-03454.02 P

TEST PROCEDURE:

DROP TEST OF TWO 1/4 SCALE

RFTP MODELS

Prepared by: J. Harjula/C. Naumenko
NED OHR
Feb-19/90

Reviewed by: M. Gavin
NED
06 MAR 90

Approved by: J.F. Tanaka/J.M. Turk
NED OHR
Mar 7/90

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1.0 INTRODUCTION

This procedure provides a step by step account of the procedures to be performed for the drop testing of two 1/4 scale RFTP models in accordance with the Test Plan, 907-TRAN-03454.03 P.

Two drop orientations are required: a 9 meter side drop and a 9 meter top edge drop. Each drop will be preceded by a helium leak test. In addition, both packages will be helium leak tested after the drop to ensure conformance to the regulatory limit on leakage.

2.0 PRE-TEST PREPARATIONS

The following are preparatory to the drop/leak testing of the 1/4 scale models.

(1) Upon receiving the completed 1/4 scale models from Bruce Construction, all major dimensions will be checked for compliance with the final revision of the manufacturer's drawings.

(2) All dimensions which do not match those specified will be noted and if these deviations are deemed to be acceptable, the manufacturer's drawings will be revised to reflect the changes.

(3) Reference measurements will be taken for the flatness of the containment lid flange and the inner bolting block. The circularity of the inner bolting block will also be measured. These measurements will be repeated after the drop tests to quantify deformation in these areas.

(4) Leak testing will be performed on both models' containment lid seals to determine what leak rate is attainable. Details of the leak testing procedure are provided in Section 4.0.

(5) All rigging (turnbuckles, shackles, swivel eyebolts, release hook, lifting rings etc.) required to drop the models in the appropriate orientations (top edge and flat side), will be assembled and tested prior to the drop. In addition, a complete set of spare rigging will be on standby should it be required.

(6) All instrumentation, (accelerometers, amplifiers, cables, tape recorder, oscilloscope etc.) required to record the drop tests of the models in the appropriate orientations, will be assembled and tested prior to the drop test day. As necessary, spares of these components will be located and on standby.

(7) Photographers, video, high speed camera and crane operators will be informed of the actual drop test schedule as early as possible to ensure their availability. They will be shown the drop test site well in advance so that they have ample time to prepare for the test. Where possible, spare photographic equipment will be located and on standby.

(8) A notice will be issued to all scheduled visitors to the drop test site informing them that hard hats and safety shoes and glasses will be required to enter the site.

(9) "Dry runs" of the complete drop test procedure will be performed to gain familiarity with all procedures and to ensure that no details have been overlooked.

(10) On the day prior to the drop test, a final visit will be made to the test site to ensure the site is ready and that all obstructing equipment is removed.

3.0 DROP TESTING PROCEDURES

The following describes the procedures for actual drop testing of the two scale models. Note that one model marked "Model A" will be dropped in the top edge orientation, while the other model, "Model B" will be dropped in the side orientation.

(1) All final test site preparations will be made. This involves setting up high speed film backdrop and positioning the instrumentation truck.

(2) The two models (which have been leak tested, see Section 4.0) will be assembled in the mechanical research lab KB-03. The entire package will be cleaned with methanol prior to assembly.

(3) The containment lid flange, bolting block and silicone seal will be thoroughly cleaned with methanol and lint-free wipes. The gasket will then be installed and 12 numbered, lubricated bolts will be finger tightened. The 12 containment lid bolts will then be torqued down in two stages, in the sequence shown in Figure 1, to 12 and 37.5 in. lbs. Having completed this, the bolts should then be untightened in reverse order recording the torque necessary to untorque the bolts on the sheet provided in Appendix A. Retorque the bolts in proper sequence in two stages.

(4) The containment vessel will be leak tested in accordance with Section 4.0.

(5) The overpack cover will then be placed and twenty-four (24) socket head cap screws (SHCS) (with lock washers) will be finger tightened.

The twenty-four (24) numbered, SHCS's will then be torqued down in two stages, in the sequence shown in Figure 1 to 12 and 37.5 in. lbs.

(6) All required lifting rigging will be attached and two accelerometers will be mounted while a final check will be made to ensure that the instruments are working correctly and that the proper drop orientation is achieved.

(7) When all key personal are ready the model will be raised to a height of 9 m and released. Model A will be dropped in the edge drop orientation, while Model B will be dropped in the side drop orientation.

(8) After each drop the photographic crew will have an opportunity to take all the required pictures. During this time, all physical damage to the model and instrumentation will carefully be noted. This will include information such as:

- which numbered bolts broke
- which instrumentation wires were clipped
- etc.

(9) After moving the model to the mechanical testing lab in KB-223, the helium leak test will be performed as described in Section 4.0. Where necessary, pictures and video will be taken.

(10) After the helium leak test, the 12 containment lid bolts will be removed in reverse order (see Figure 1) and the amount of torque required to remove each bolt will be noted on the sheet in Appendix A. An examination of the containment lid seal and payload will then take place.

(11) The model will then be set aside in a safe area. NO ANALYSIS OF DATA WILL BE PERFORMED AT THE DROP TEST SITE AND NO INFORMATION REGARDING THE TEST WILL BE RELEASED UNTIL SUFFICIENT TIME HAS BEEN SPENT TO CAREFULLY ANALYZE THE DATA. RMTU will make a tentative statement of test results with a final result available in 1-2 days.

(12) Following the tests, the flatness of the containment lid flange and inner bolting block will be measured, as well as the circularity of the inner bolting block. This data will be compared to the pre-drop data to determine the relative deformations in these areas. Other pertinent measurements regarding deformation of the outer skins, etc., will be made.

(13) All containment welds will be inspected either visually or by liquid penetrant.

(14) A draft report outlining the results of the tests will be promptly issued, followed by a final report.

4.0 HELIUM LEAK TESTING

The following describes the procedures to be followed when helium leak testing the packages before and after the drop tests.

The following assumes that the containment lid gasket and lid are in place and the bolts torqued to their specified values. It is also assumed that the helium leak detector has been properly calibrated using a known helium leak.

(1) Using the test port, the containment lid boundary will be evacuated and backfilled with helium to .25 atm abs. of helium.

(2) The area external to the package will then be purged with nitrogen to remove any trace amounts of helium.

(3) The model will then be placed in a bell jar. The helium leak detector will be connected to the bell jar and the bell jar will be evacuated through the roughing pump of the helium leak detector.

(4) When less than 100 millitorr pressure is detected in the bell jar the leak test will commence.

(5) The leak rate will be monitored and recorded for thirty minutes.

5.0 TEST REPORT

The test report shall report the following data:

(1) Model drawings, approved by NED.

(2) Before and after circularity of inner bolting block and gross deformations of outer shell.

(3) Before and after flatness of containment gasket groove.

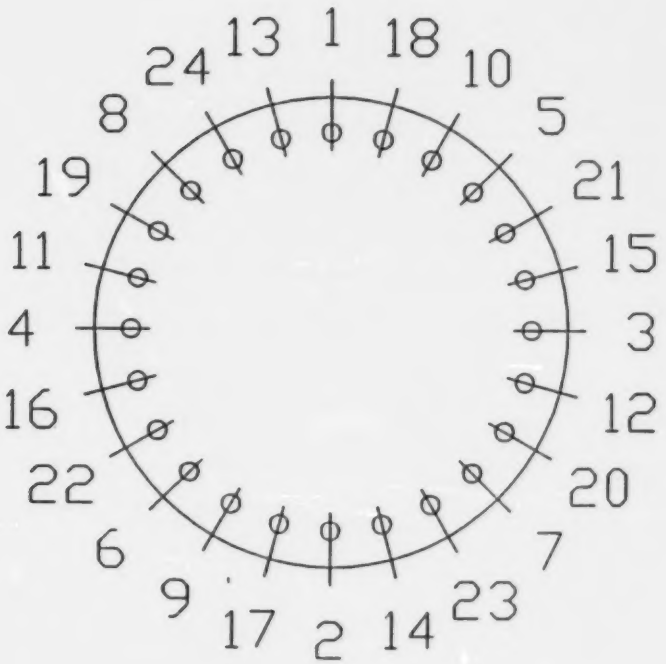
(4) Before and after leak rates.

(5) Accelerometer readings.

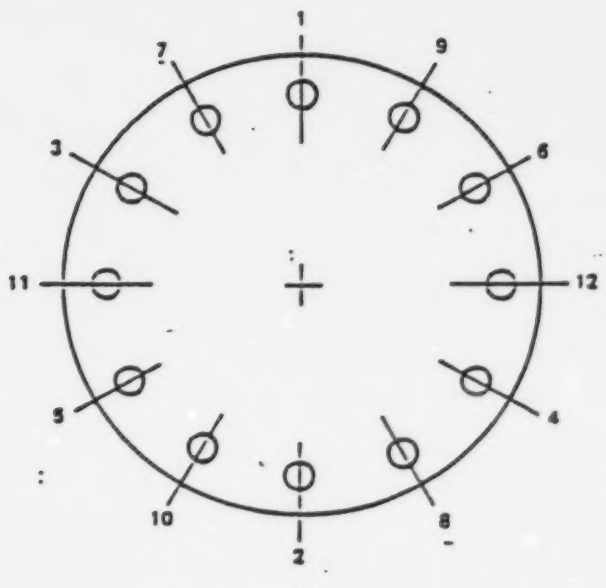
(6) Before and after bolt torques for containment lid and overpack.

Figure 1: Bolt Torquing Patterns

24 Bolt Sequence



12 Bolt Sequence



APPENDIX A

Data Sheet For Containment Lid Bolt Torques

Model _____

Bolt #	Pre-Test Release Torque (In lbs)	Post-Test Release Torque (In lbs)
1		
2		
3		
4		
5		
6		
7		
8		
9		
10		
11		
12		

Overpack Cover Bolts Lost During Impact

Number of BOLTS:

Bolt Numbers -

Appendix D: Photographs

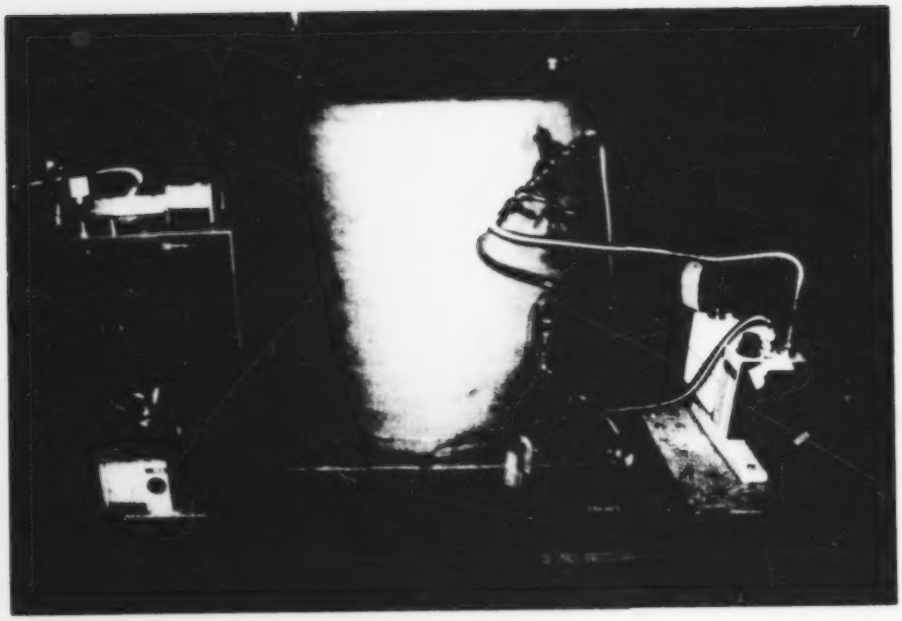


Figure D1: Leak Test Apparatus and Equipment

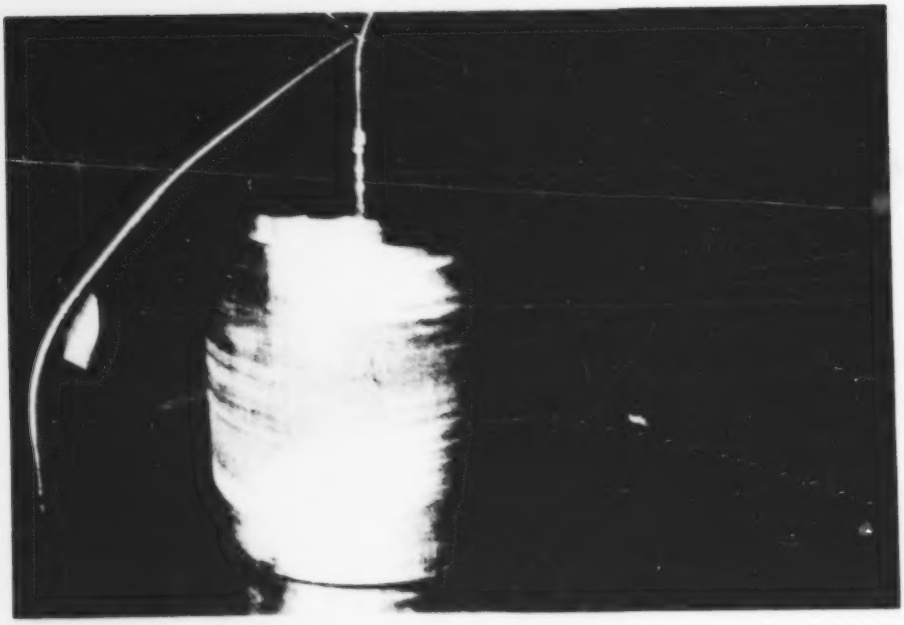


Figure D2: Inner Container of Model Connected to Bell Jar Base

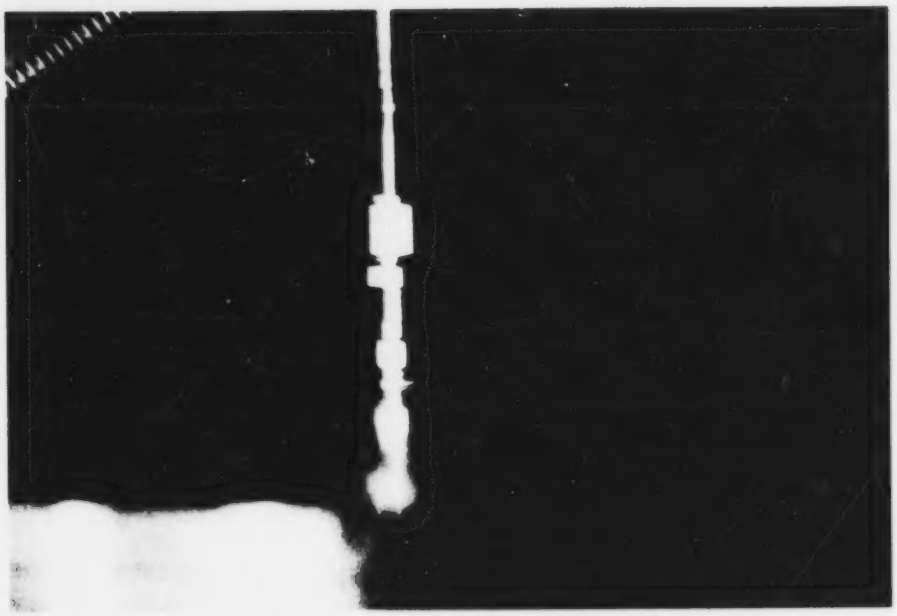


Figure D3: Fitting Connecting to Inner Container Lid of Model

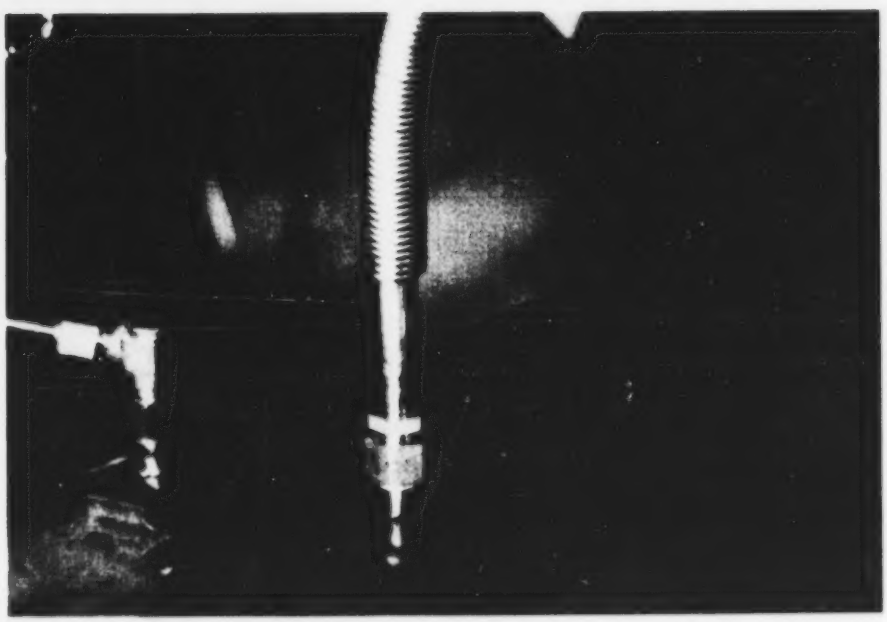


Figure D4: Feedthrough Fittings from Inside to Outside of Bell Jar

Figure D5: Accelerometer on Accelerometer Mount

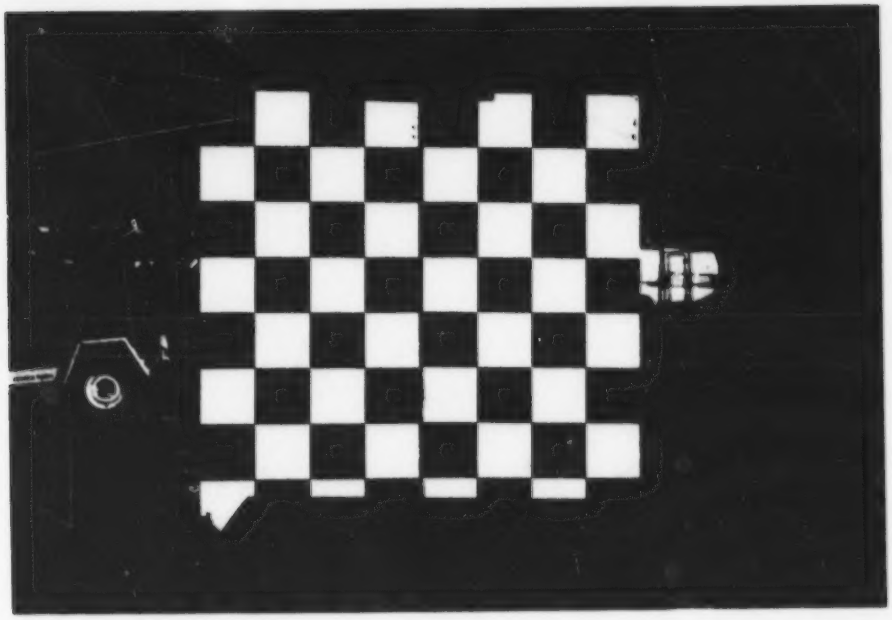


Figure D6: Drop Test Site with Backdrop and Target Mass

Figure D7: Post Top Corner Drop Model (Model A) Overall Damage

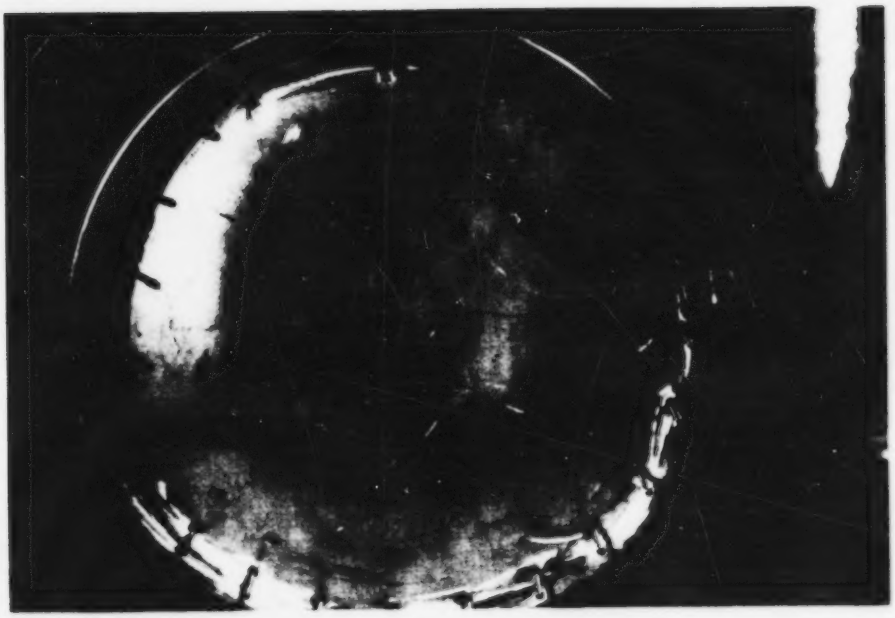


Figure D8: Post Top Corner Drop Model (Model A) Overpack Lid (Bottom View)

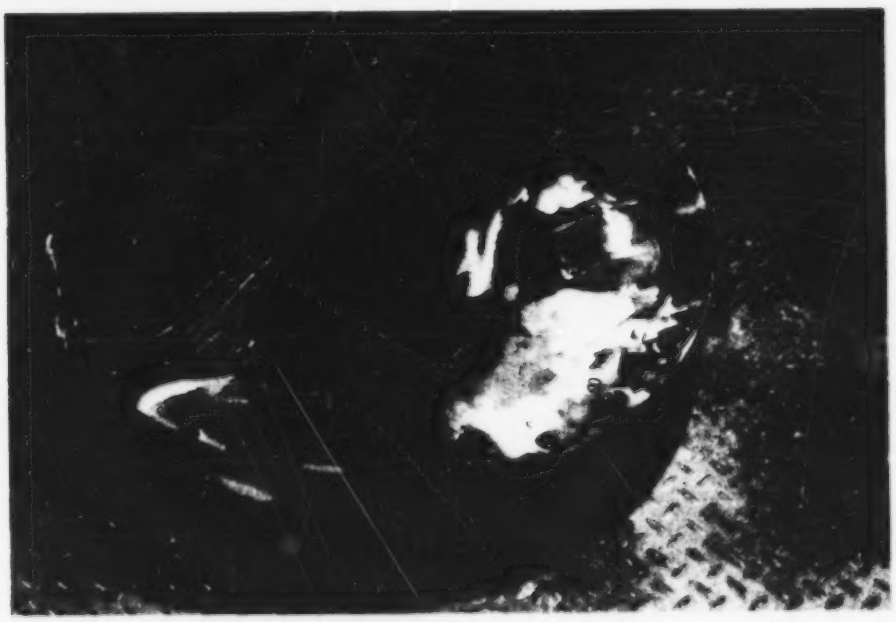


Figure D9: Post Top Corner Drop Model (Model A) Overpack Lid (Top View)

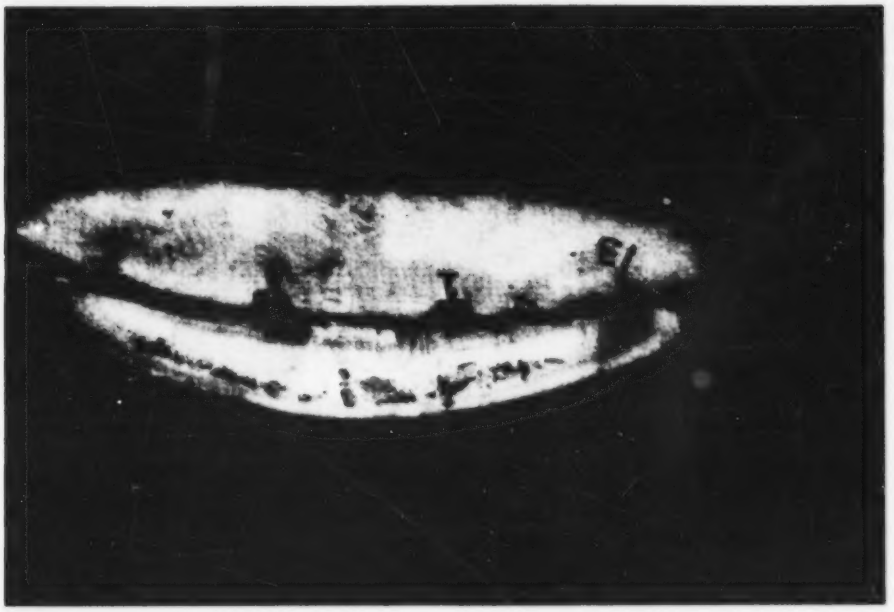


Figure D10: Post Top Corner Drop Model (Model A) Overpack Lid (Top View)

Figure D11: Post Top Corner Drop Model (Model A) Overpack Lid (Top View)

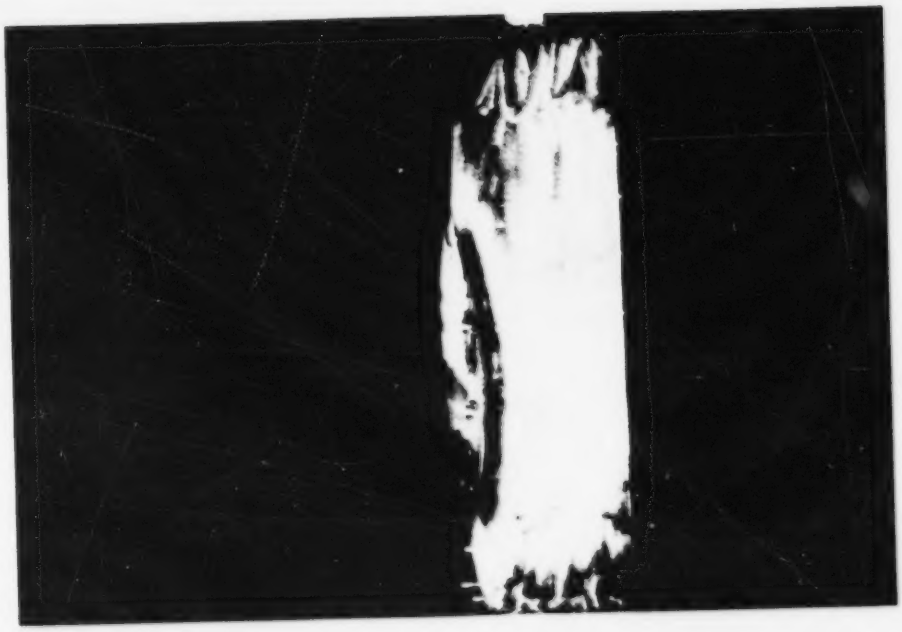


Figure D12: Post Top Corner Drop Model (Model A) Overpack Lid (Side View)

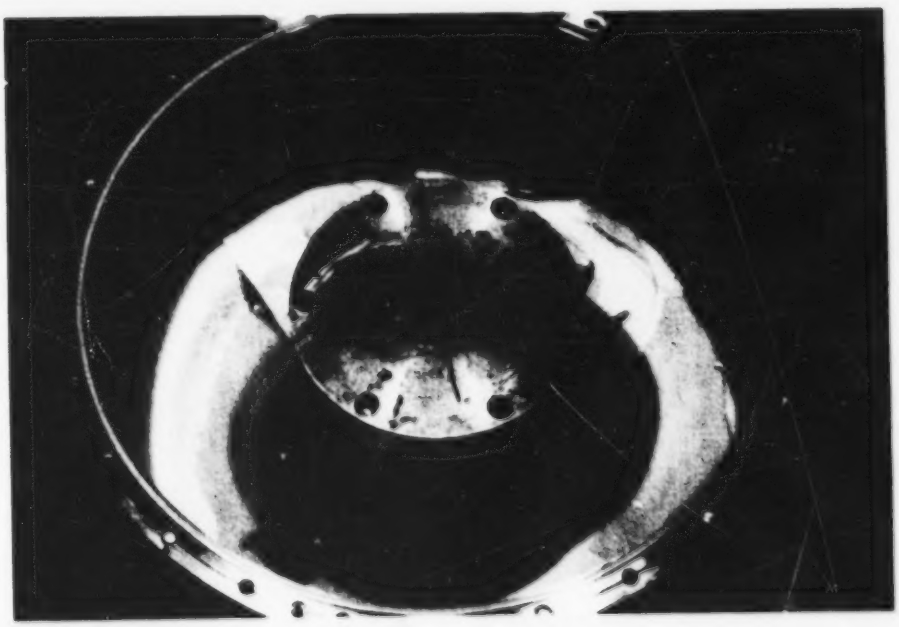


Figure D13: Post Top Corner Drop Model (Model A) Inner Container with Dunnage and Payload

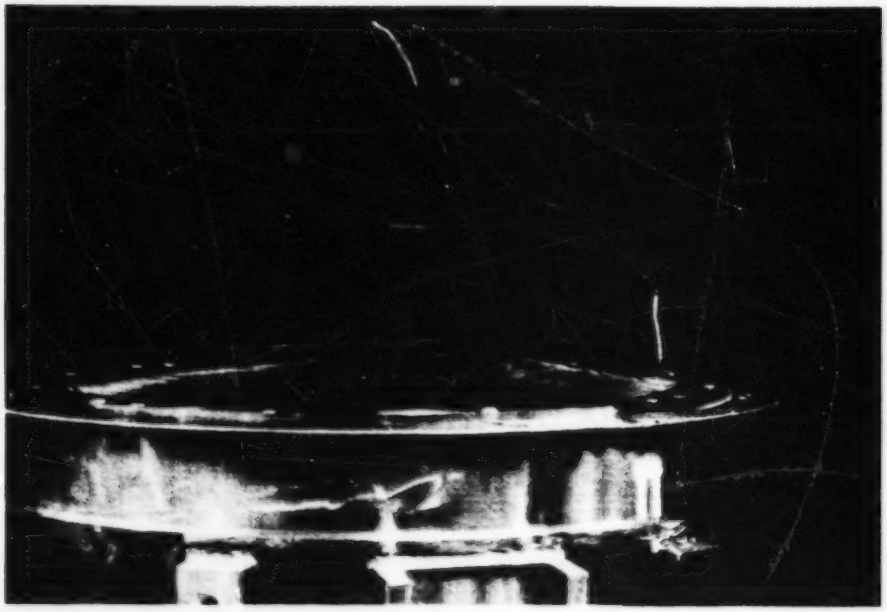


Figure D14: Post Top Corner Drop Model (Model A) Overpack Body with Inner Container and Lid

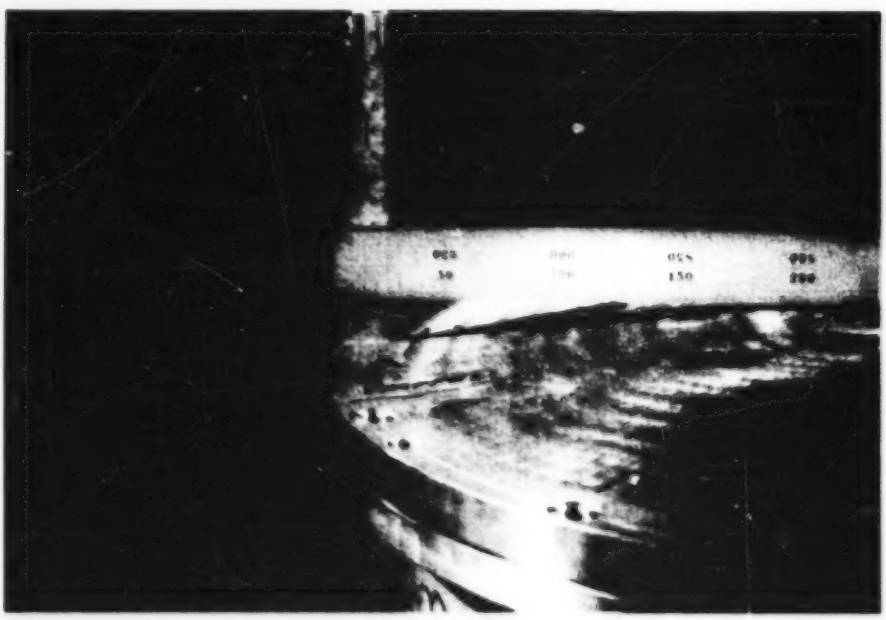


Figure D15: Post Top Corner Drop Model (Model A) Inner Container Body and Lid

Figure D16: Post Top Corner Drop Model (Model A) Bottom Dunnage (Top View)

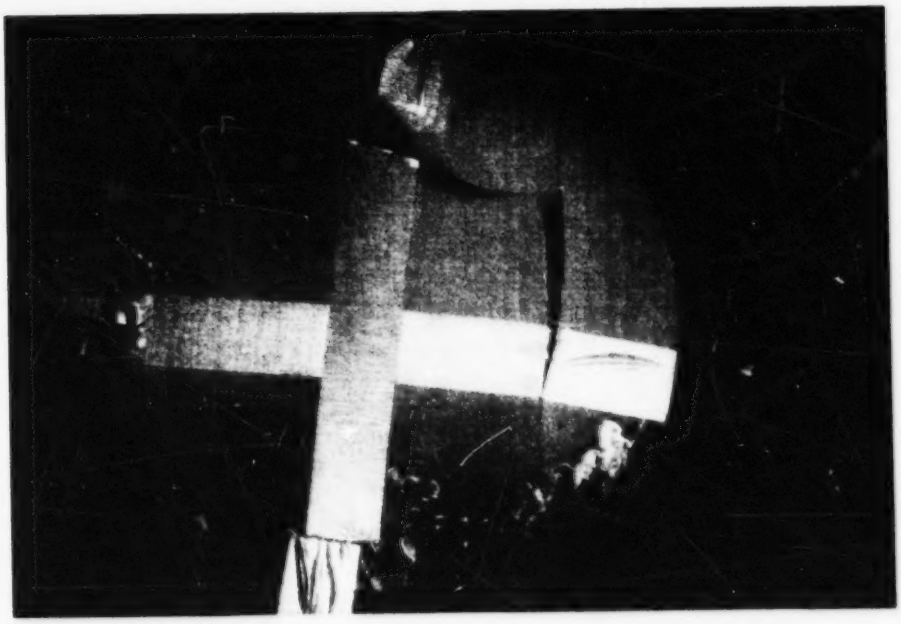


Figure D17: Post Top Corner Drop Model (Model A) Bottom Dunnage (Bottom View)

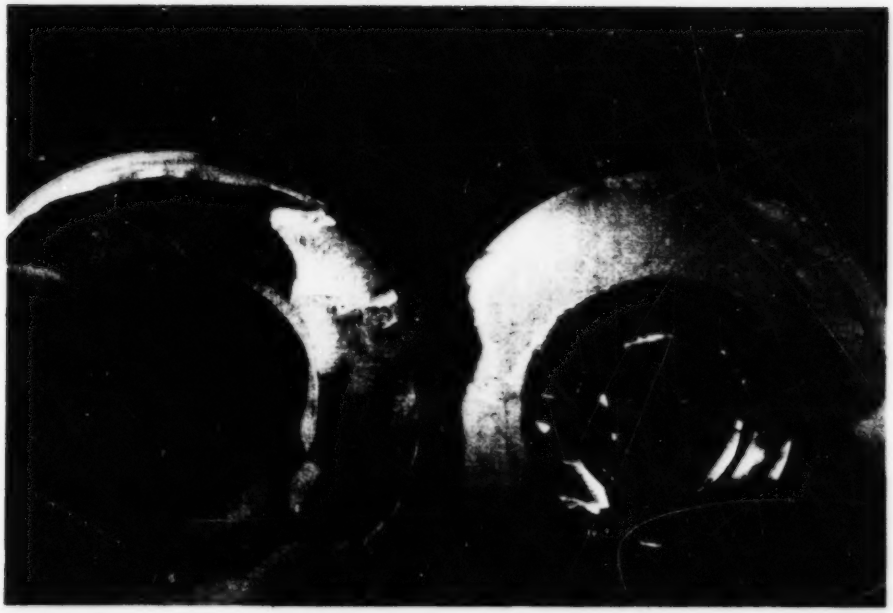


Figure D18: Post Top Corner Drop Model (Model A) Top Dunnage (Split Section View)

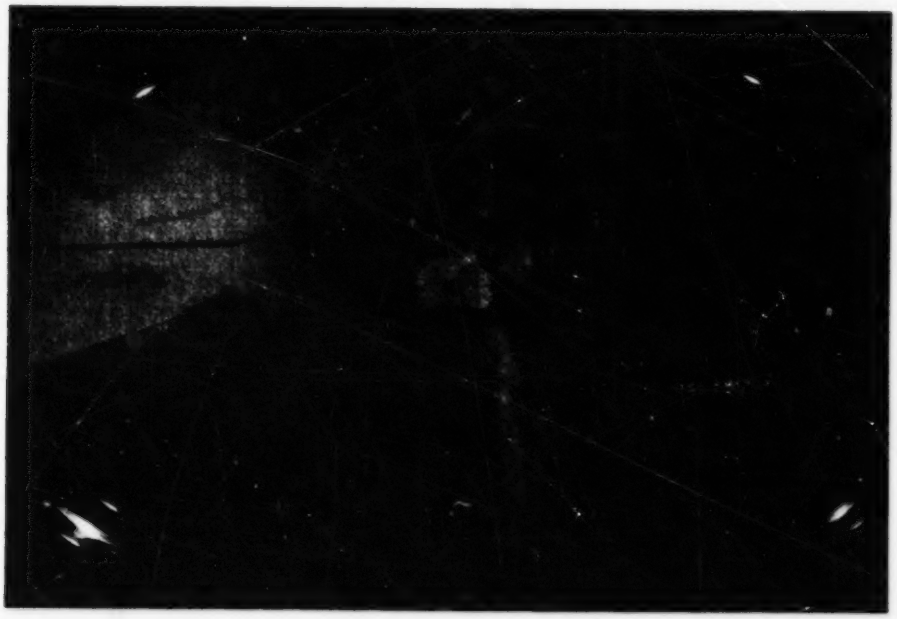


Figure D19: Post Top Corner Drop Model (Model A) Top Dunnage (Top View)

Figure D20: Post Top Corner Drop Model (Model A) Top Dunnage Lifting Mount Penetration

Figure D21: Post Flat Side Drop Model (Model B) Overall Damage

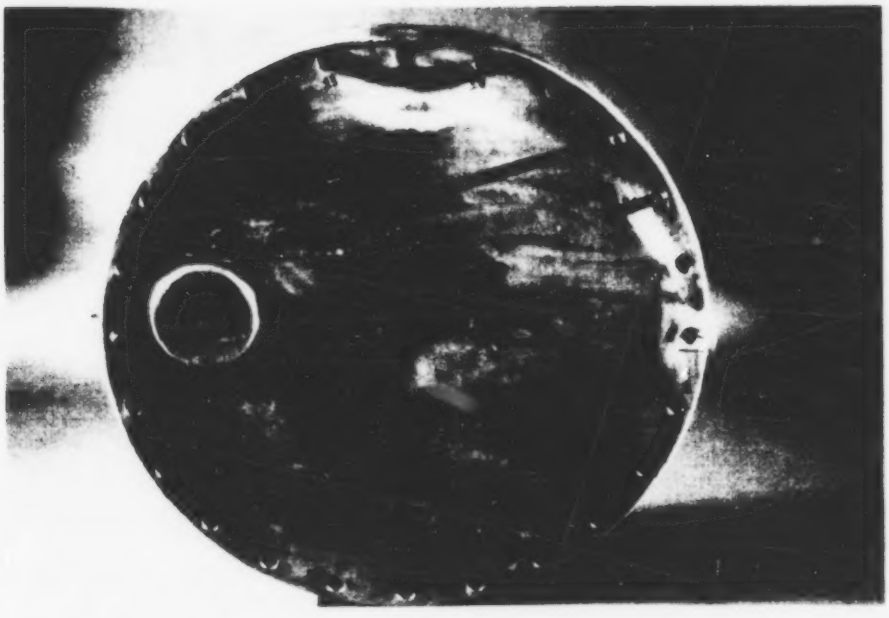


Figure D22: Post Flat Side Drop Model (Model B) Overpack Lid (Top View)

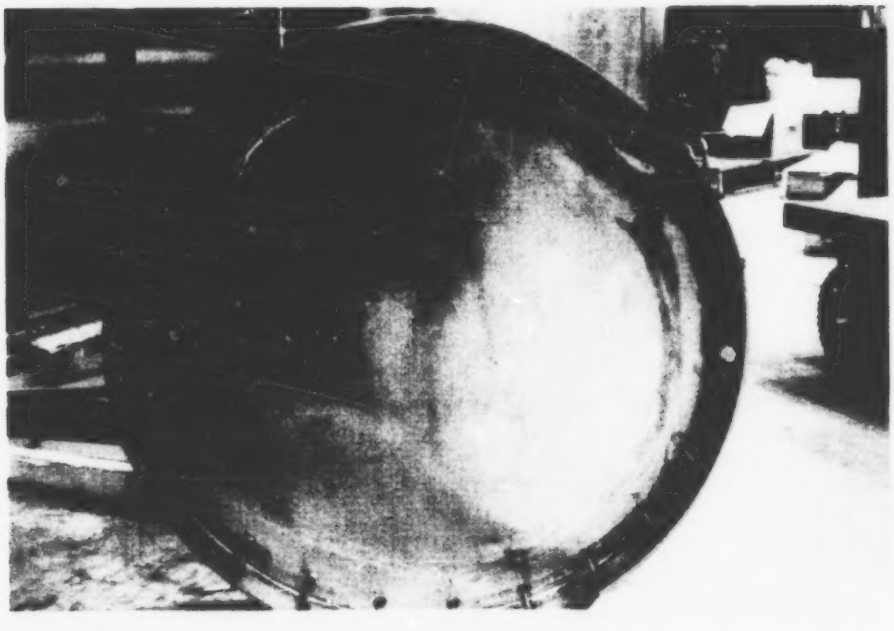


Figure D23: Post Flat Side Drop Model (Model B) Overpack Lid (Bottom View)

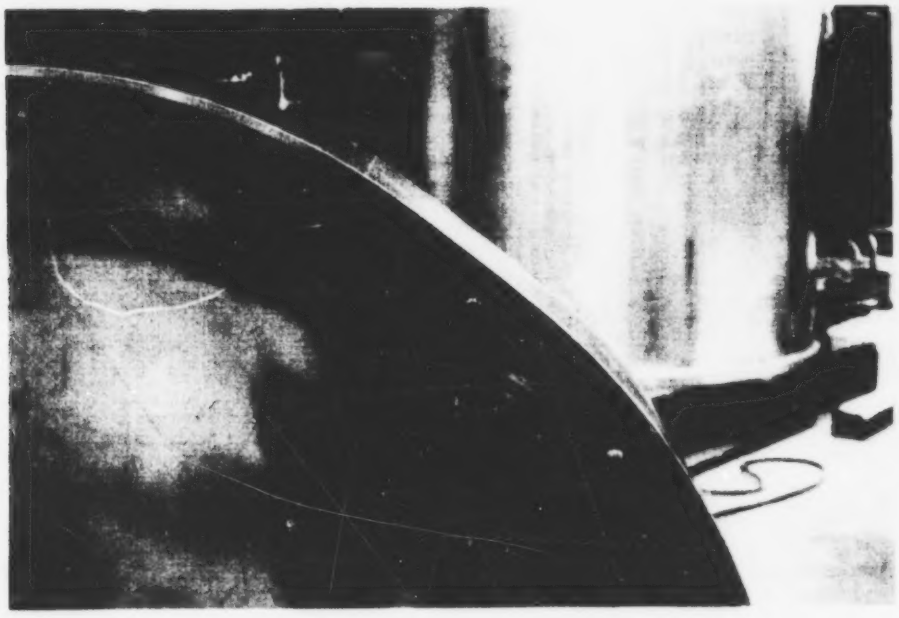


Figure D24: Post Flat Side Drop Model (Model B) Overpack Lid (Bottom View)

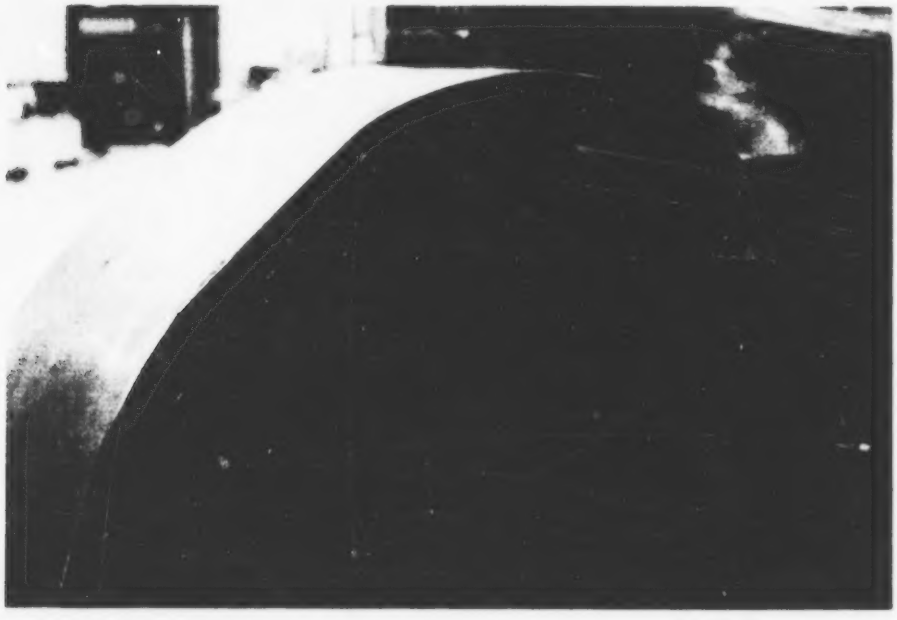


Figure D25: Post Flat Side Drop Model (Model B) Overpack Lid (Top View)

Figure D26: Post Flat Side Drop Model (Model B) Overpack Lid (Top View)

Figure D27: Post Flat Side Drop Model (Model B) Overpack Lid (Top View)

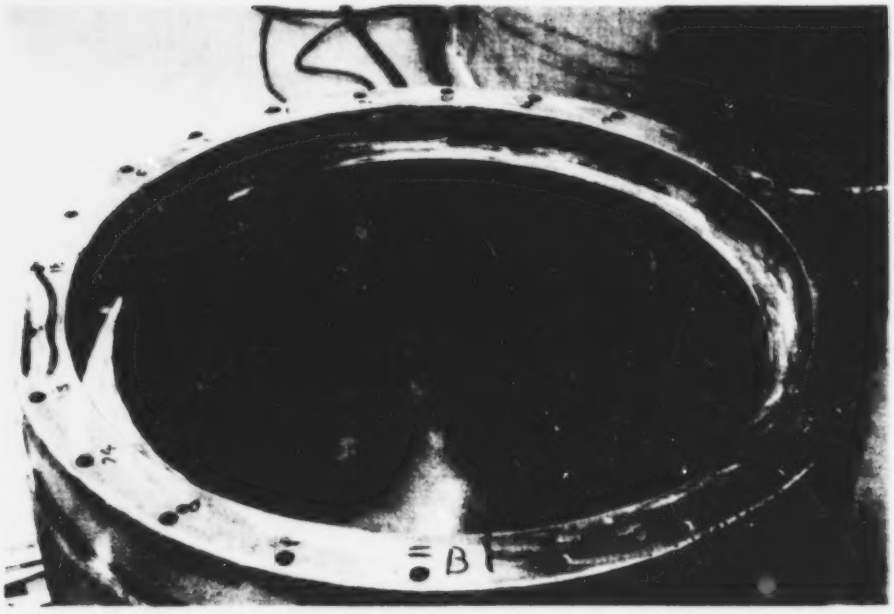


Figure D28: Post Flat Side Drop Model (Model B) Overpack Body Damage (Top View)

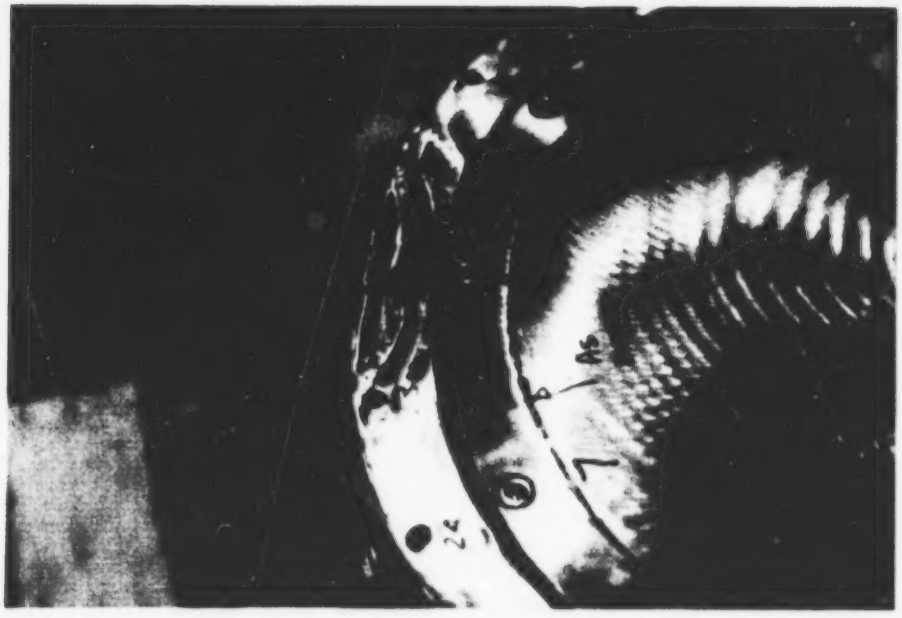


Figure D29: Post Flat Side Drop Model (Model B) Overpack Body Damage (Top View)

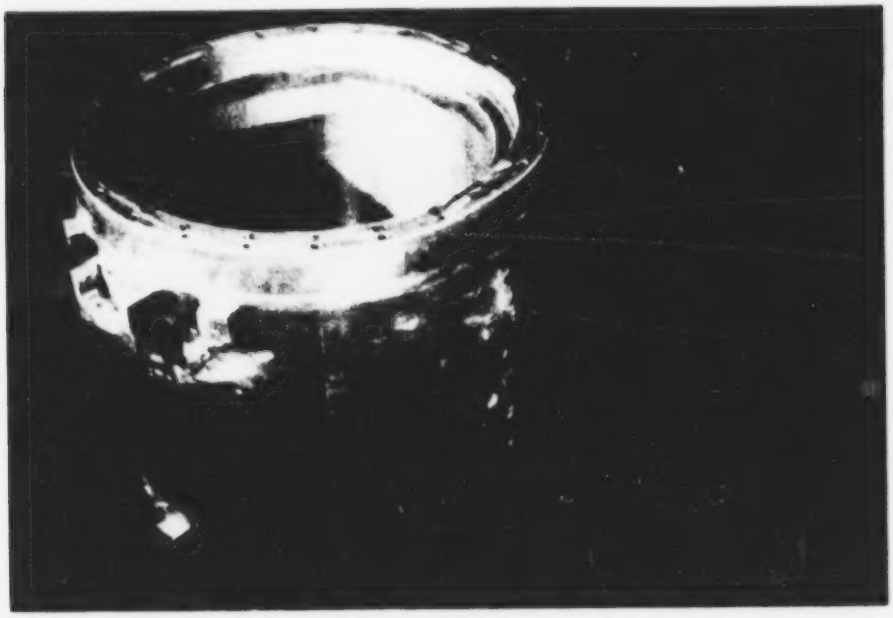


Figure D30: Post Flat Side Drop Model (Model B) Overpack Body

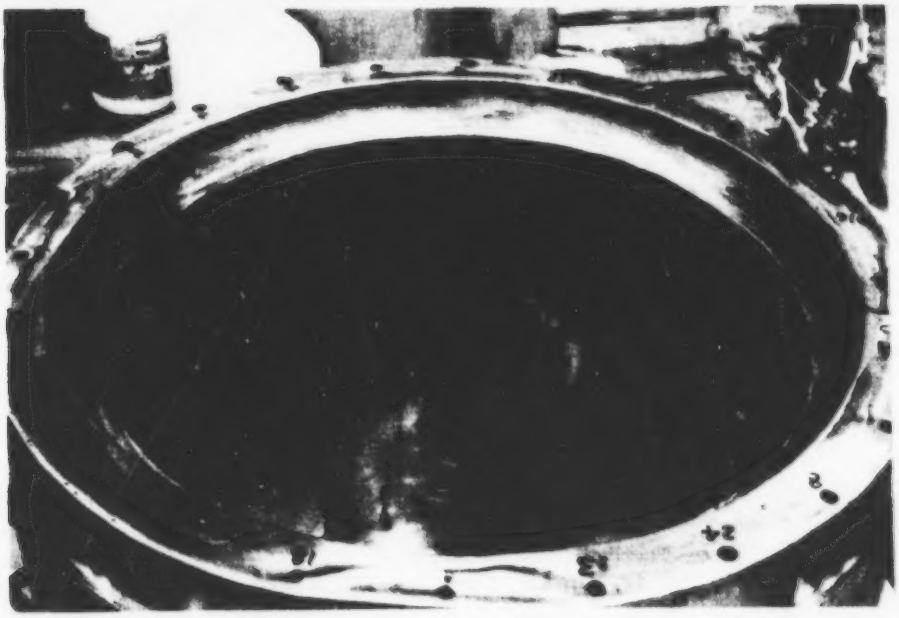


Figure D31: Post Flat Side Drop Model (Model B) Overpack Body

Figure D32: Post Flat Side Drop Model (Model B) Overpack Lid/Body Joint (Opposite From Impact Side)

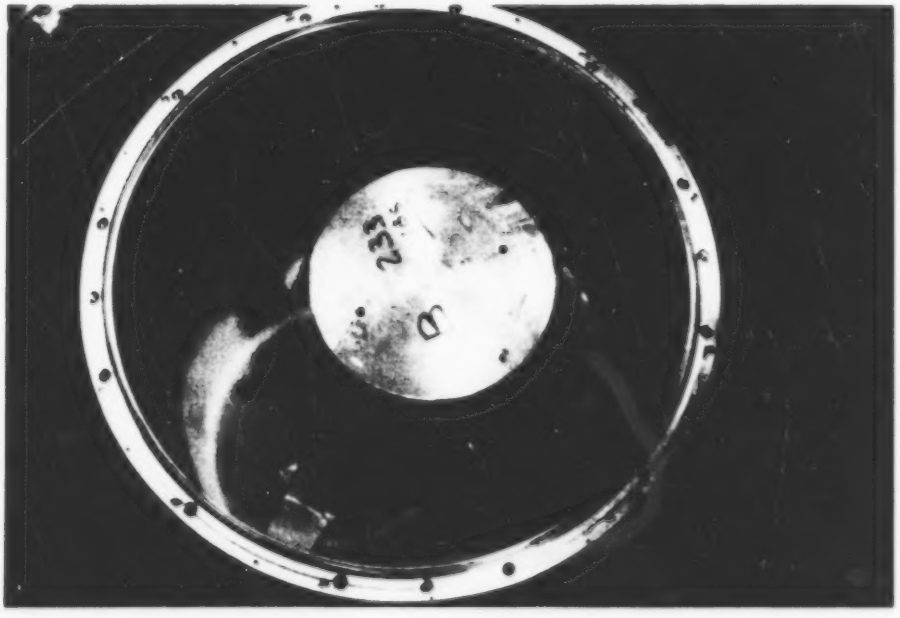


Figure D33: Post Flat Side Drop Model (Model B) Inner Container with Dunnage and Payload

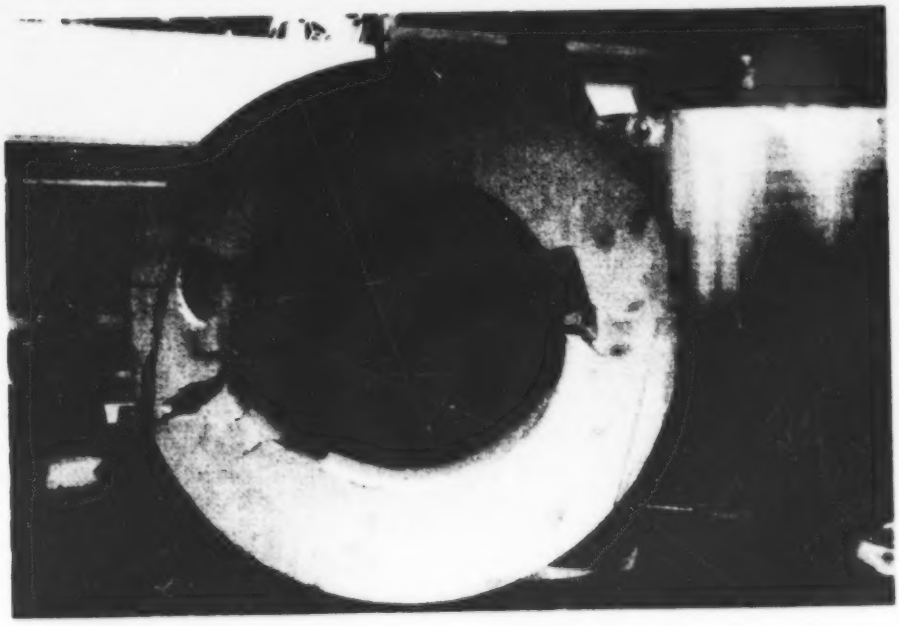


Figure D34: Post Flat Side Drop Model (Model B) Top Dunnage (Bottom View)

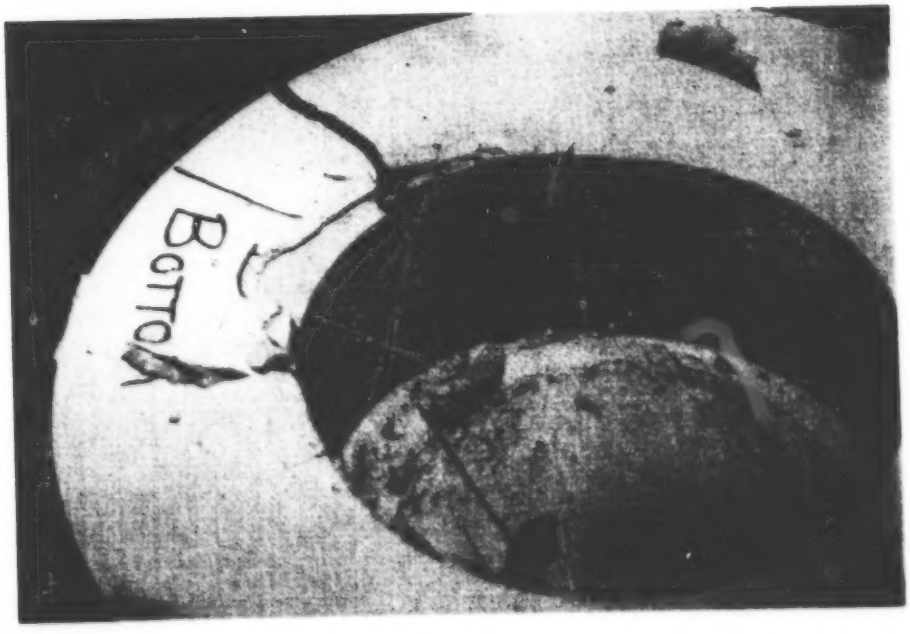


Figure D35: Post Flat Side Drop Model (Model B) Bottom Dunnage (Top View)

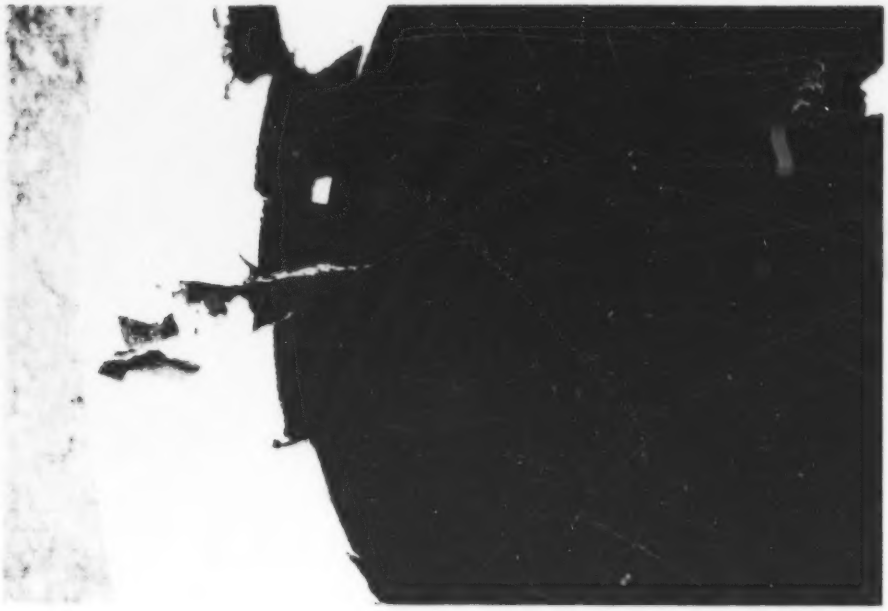


Figure D36: Post Flat Side Drop Model (Model B) Top Dunnage Lifting Mount Penetration

Figure D37: Post Flat Side Drop Model (Model B) Top Dunnage Lifting Mount Penetration